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SUSPENDED SEDIMENT AND PHOSPHORUS BUDGET AND TROPHIC STATUS OF BUKIT MERAH RESERVOIR, PERAK, MALAYSIA

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Abstract

Bukit Merah Reservoir (BMR) is one of the 51 impoundments in Malaysia. BMR is the oldest reservoir built in the early 1900s originally to store water for irrigation, but nowadays its functions include also flood control and water supply. Nowadays, it is threatened by land use change in the upper catchments and surrounding activities, which feeding eroded material and chemicals into the reservoir. Suspended sediment, as well as, nutrient fluxes into BMR are becoming an increasing threat to the reservoir, as its sedimentation and eutrophication accelerate. This paper discusses our study on the BMR carried out between March 2008 and April 2009 to assess the water quality status, and to determine the sediment and Total Phosphorus (TP) influx into the south pool lake. An estimated amount of suspended sediment fluxes of about 2,900 t year^{-1} came from the north pool lake (18%) and 12,900 t year^{-1} from the main Kurau River inlet (82% of the total input to the BMR). Of these total sediment input (nearly 15,800 t) about 5,600 t (36%) of the total sediment influx was trapped in the BMR. TP influx was about 18.8 t year^{-1} and about 7 t (37%) was trapped in the reservoir. The amount sediment and TP stored in the BMR affect the water quality of the lake, therefore the mean trophic state of the lake is eutrophic (TSI of 54.4) related to high productivity. Increasing sediment input into the reservoir has affected the reservoir volume and frequent flooding downstream of the reservoir during rainy seasons, while eutrophication has caused the lake water quality deterioration.

Keywords: suspended sediment, total phosphorus, eutrophication, trophic state, Bukit Merah Reservoir

INTRODUCTION

Suspended sediment is an important source of phosphorus (P) to freshwater ecosystems including many lakes and reservoirs (Wetzel, 2001). The use of fertilizers in order to increase crop yield in catchments (Hart et al., 2004) can increase pressure on aquatic systems. Terrestrial soils provide the parent material from which sediments are derived, and therefore the speciation of P in lake sediments may be largely governed by the P contents of the catchment soils. However, the selective erosion and transportation of eroded material with different grain sizes in overland and stream flow may alter the composition of suspended sediments related or relevant to the bulk source material.

The transport of sediment-associated nutrients such as phosphorous (P) from the soil to the river network is complex, because it is influenced by many processes such as soil erosion, sediment transport, and deposition within the catchment (e.g., Gburek et al., 2000). Sediments can function either as sources or losses of phosphorous. Sedimentary P can act as an internal load to the overlying water column for a long period (Pant and Reddy, 2001).

Total phosphorus (TP) loading resulting from watershed development has long been recognized as an important factor affecting lake trophic status (Vollenweider, 1968; Dillon and Kirchner, 1975; Canfield, 1983). The effect of excessive TP loading to shallow lakes is especially pronounced as it can lead to high macrophyte production, which on senescence contributes significant amounts of nutrients to both sediments and overlying waters (Nichols and Keeney, 1973; Carpenter, 1980; Carignan and Kalff, 1982; Sabah and Wanganeo, 2008). Lake enrichment resulting from the mobilization of TP from watersheds is often, over time, followed by internal TP loading from bottom sediments (Ahlgren et al., 1988; Nürnberg, 1984; Nürnberg and Lazerte, 2004; French and Petticrew, 2007). Exploration of the geochemical association and potential bioavailability of particulate P is required, since once P is introduced to lake ecosystems it will accumulate in the bottom sediments. The stored P in the sediment can be released into the overlying water under some environmental conditions, which may have a significant impact on water quality and ultimately result in continuing eutrophication (Lennox, 1984; Abrams and Jarrell, 1995; Xie et al., 2003).

Phosphorus release is influenced by a variety of environmental factors including water temperature, pH, phosphorus, dissolved oxygen (DO), nitrate, redox potential and hydrological conditions (Jensen and Andersen 1992; Gao et al. 2005; Zhu et al., 2007). Phosphorus distribution in lake sediments is not uniform over an entire lake and environmental conditions are equally variable. Consequently, the release of phosphorus and the factors affecting this release is likely to vary within a lake. According to Carlson (1977), the accuracy of the index values based on TP depends on the assumption that phosphorus is the main algal biomass limiting factor, and that the concentration of all forms of phosphorus present in the water body is a function of algal biomass.

Bukit Merah Reservoir (BMR) in Malaysia is under threat from eutrophication due to increased intensity of agriculture in the upper catchments, agricultural development and an eco-tourism development surrounding the lake. Recent work has highlighted the growing problem of siltation (Ismail et al. 2010) and attention is now turning to nutrient fluxes. Against this background, this paper, aims to quantify suspended sediment and nutrient loadings into BMR and assessing the trophic status of the lake.

MATERIALS AND METHODS

Study area

The climate of BMR is an equatorial with an average daily temperature ranging from 23°C to 33°C. The mean annual rainfall recorded at BMR for the period 1953–2008 was 2905 mm (range 2200–3700 mm/year). The river inlets to BMR, are the Merah (M) River, Jelutong (J) River, Selarong (S) River and Kurau (K) River (Fig. 1). The river discharge of Merah, Jelutong, Selarong river are low with an average discharge of 1.03$\pm$0.59 m^3/s, 1.04$\pm$0.47 m^3/s and 0.11 $\pm$0.1 m^3/s, respectively. Major input to BMR lake is from Kurau River with an average discharge of 27.2 m^3/s ranging from 6.6-65.7m^3/s. The capacity of the reservoir is 70×10^6 m^3 at a water level depth of 8.5 m asl (Ismail et al. 2010).

Based on the data the Department of Survey, Malaysia, the land use of the BMR catchment area comprises oil palm (48.3 km^2); rubber (98.9 km^2); forest (196.9 km^2); paddy (15.5 km^2); and others (47.9 km^2) (Hidzrami, 2010). The land use changes in the catchment area covering the Merah, Jelutong and Selarong sub-catchments have also been described by Amirin and Hasmadi (2010). They found that from 1989 to 1999, forest cover decreased from 64% to 60% and 94% of bushes were mostly replaced by oil palm. The areal extension of oil palm plantations increased by 13% and of the paddies it increased by as much as 65%.

Field measurement and sample collection

The sampling programme reported here covers a one-year period from March 2008 to April 2009 on several monitoring sites of the BMR (Fig. 1). The locations of the monitoring sites for the physico-chemical and biological variables of the river inputs and the reservoir outputs namely the Kurau outlet and canals are represented on Fig. 1. Measurements of water quality and river flow were undertaken every fortnight at Kurau River (K) and at the north pool outlet (ONP). River flow were measured using current meter and discharge was calculated using a velocity-area method (Shaw, 1994). Discharge in the main inlets and the outlets was measured, and the water level was recorded continuously. In minor inlets and a few outlets, discharge was measured fortnightly and some time daily during rainy period. Mean discharge was estimated by establishment of relationships between these instantaneous values and the calculated mean discharge from nearby hydrometric stations.

The topmost water layer of BMR (at 0.5m depth) was analysed in situ for pH, dissolved oxygen (DO) using a portable field pH meter (YSI Portable meter), described by Ismail and Najib (2011) and Ismail et al. (2010). Water transparency was tested using Secchi disk. Water samples were collected every fortnight and analysed for suspended sediment concentration (SSC), total phosphorus (TP) concentrations and chlorophyll-a based on APHA standard methods (APHA 1989). SSC was determined by filtration using 0.45-µm Whatman GFC filter papers and oven drying at 105°C for 24 hours (APHA, 1989). TP concentrations were determined with

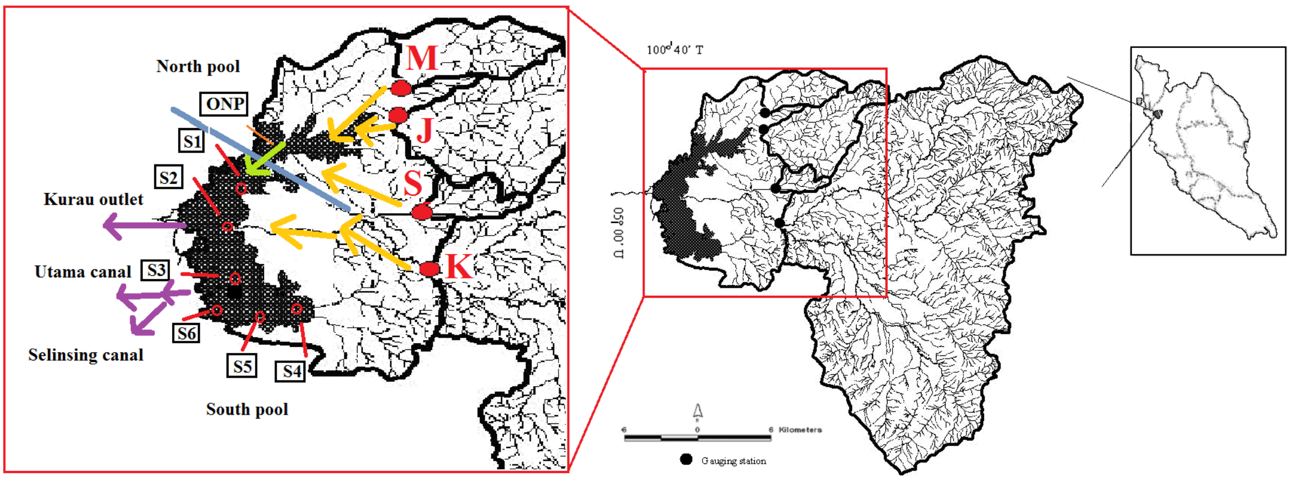

Fig 1 Bukit Merah Reservoir (BMR) and its catchment area located at north Perak. The reservoir receives inputs from Kurau (K), Selarong (S), Merah (M) and Jelutong (J) Rivers. Six sampling stations in the lake are shown for S1 to S6. The water from the lake flows out of the system through the Kurau outlet and 2 irrigation canals (Selinsing and Utama canal). Yellow arrows show the input from the catchment, green arrow is the output from north pool and purple are output arrows from the south pool.

the ascorbic acid method (APHA, 1989), while chlorophyll-a was extracted with acetone for 48 h under dark and cold conditions (3–5 °C). The transmittance percentage of the extracts was read at 664-665 nm using a Perkin Elmer 25 UV–Vis spectrophotometer following APHA (1989). The estimation of sediment and nutrient loading is expected to be underestimated due to the sampling frequency, as during storms samples were not taken.

Trophic Status Index (TSI)

This study used Carlson's Trophic State Index (TSI), also known as the Carlson Index, which was developed to compare Secchi disk depth (SD), chlorophyll-a concentrations and TP concentrations (Carlson, 1977), thus to classify regional surface waters, including streams and rivers. Although chlorophyll-a is the most direct measure of algae biomass, Carlson used Secchi disc depth as the primary indicator since these three variables are highly correlated and are considered good estimators of algal biomass. The TSI was determined by the first three equations (Eq. 1, 2 and 3) where TSI is in natural logarithm, and Carlson TSI (Eq. 4) is the average of the three TSI.

$$TSI\ (SD) = 60 - 14.41 \ln (SD) \qquad \text{(Eq. 1)}$$

where SD is mean Secchi disc depth (m)

$$TSI\ (Chla) = 9.81 \ln (Chla) + 30.6 \qquad \text{(Eq. 2)}$$

where Chla is mean chlorophyll-a (µg L^{-1})

$$TSI\ (TP) = 14.42 \ln (TP) + 4.15 \qquad \text{(Eq. 3)}$$

where TP is mean total phosphorus (µg L^{-1})

$$\text{Carlson's } TSI = [TSI\ (SD) + TSI\ (Chla) + TSI\ (TP)]/3 \qquad \text{(Eq. 4)}$$

The TSI range is related to productivity. A range between 40-50 is usually associated with mesotrophy (moderate productivity). Index values greater than 50 are associated with eutrophy (high productivity), while values less than 40 refer to oligotrophy (low productivity).

Data analysis

Loadings of nutrients and suspended sediment in tonnes (t) between time interval K, were calculated by multiplying the discharge Q (m^3 s^{-1}) by concentration S (mg L^{-1}) over the time interval K (seconds) between samples based on the average sample load approach (Littlewood, 1992).

RESULTS

Sediment and phosphorus budget

The simplified sediment and TP budget between the river inputs (Kurau River and outlet from north pool) and the outputs (Kurau outlet and Selinsing and Utama Canals) is summarised in Table 1. The south pool lake received sediment inputs from Kurau River (K) and outlet from north pool (ONP) totalling almost 15,800 t year^{-1} and about 19 t year^{-1}of TP load. Kurau River, which is the main river inlet to the BMR, contributed almost 82% of the total sediment input, amounting to about or 12,900 t year^{-1}, while the TP load about was 11 t year^{-1} (60% of the total) during the study period. During the studied year-long period water discharge, Q (m^3s^{-1}) and suspended sediment loading of Kurau River altered considerably (Fig. 2). Higher Q and SS loads were observed from September to December 2008 (the north-east monsoon period), and April 2009 (early onset of inter-monsoon month).

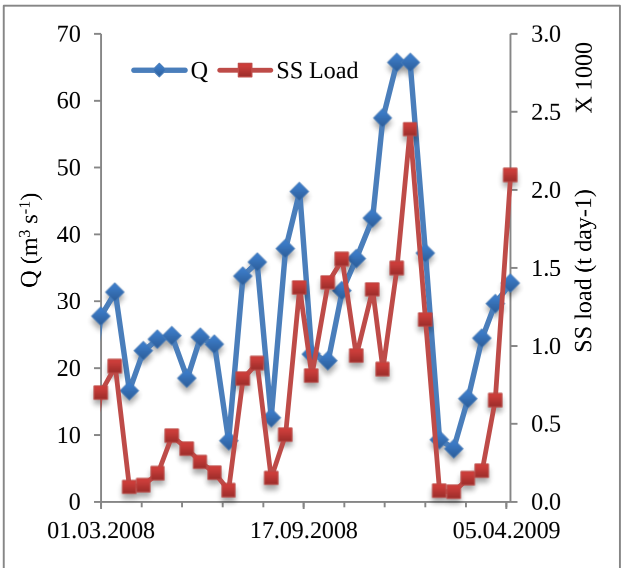

Fig. 2 Water discharge (Q) in m^3 s^{-1} and suspended sediment loads (t day^{-1}) of Kurau River during the study period

Table 1 Sediment and phosphorus budget for Bukit Merah Reservoir (2008-2009)

	Suspended sediment load (t)	Percentage (%)	Total Phosphorus load (t)	Percentage (%)
Kurau River (K)	12871.5	81.6	11.32	60.3
Ouput from north pool (ONP)	2899.6	18.4	7.45	39.7
Total Input	15771.2	100	18.77	100
Output				
Utama canal	4783.1	47.1	5.60	47.5
Selinsing canal	1461.4	14.4	0.92	7.8
Kurau outlet	3912.0	38.5	5.26	44.7
Total Output	10156.5	100	11.78	100
Input–Output	5614.6	35.6	6.99	37.2

The total amount of suspended sediment flushed out from the lake system through the Kurau outlet was about 3,900 t year^{-1} (38.5%), besides, nearly 4,800 t year^{-1} (47%) was delivered through the Utama canal and 1,500 t year^{-1} (14%) through the Selinsing canal. Thus, altogether the total sediment output from the reservoir was 10,157 t year^{-1}. It was estimated that approximately 5615 t (36%) of the sediment delivered in 2008 to 2009 was trapped in the reservoir (see Table 1).

The total amount of TP flush out of the lake system through the Kurau outlet was 5.3 t year^{-1} (45 % of the total outflux); while 5.6 t year^{-1} (47.5 % of the total outflux) were through the Utama canal and only 0.92 t year^{-1} (8%) through the Selinsing canal, amounting to a total TP output about 12 t year^{-1}. Hence, it can be estimated that approximately 37% of the TP was stored in the reservoir (see Table 1).

Relationship between SSC and turbidity

The relationship between SSC and turbidity at Kurau River and outlet from north pool (ONP) are shown on Fig. 3 and 4. The relationship was good with $R^2 = 0.73$ and $R^2 = 0.65$, respectively. Previous studies in 2007, including Ismail et al. (2010) showed that the mean SSC in the lake was 8.61 mg L^{-1} ranging from 0.93 mg L^{-1} in the dry months to 38.0 mg L^{-1} in the rainy season (Table 2). The mean SSC was higher in 2008 (13.5 ± 19.98 mg L^{-1}). The mean turbidities in 2007 and 2008 were 12.4 and 23 NTU, respectively. The Secchi disk depth, which is inversely related to SSC and turbidity, was higher in 2007 (mean = 0.85 m) than in 2008 (mean = 0.74 m) (see Table 2).

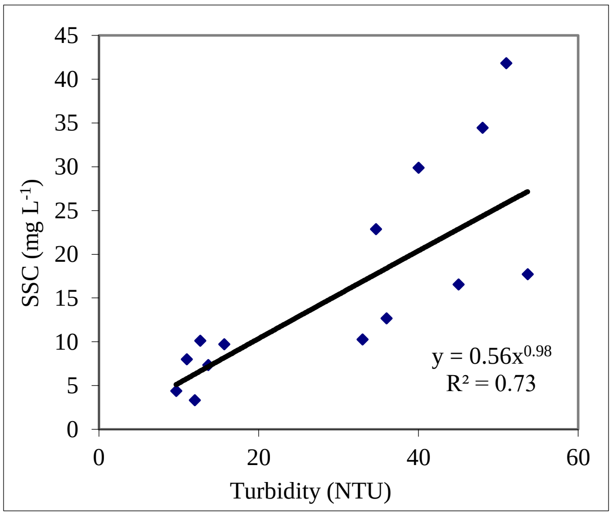

Fig. 3 Regression SSC and turbidity at Sg. Kurau

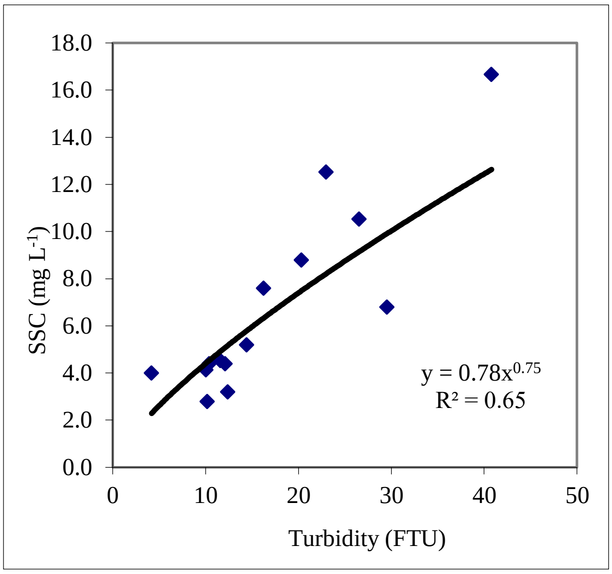

Fig. 4 Regression between SSC and turbidity at outlet from the north pool

TP and SSC relationship

Fig. 5 and 6 shows the relationship between TP contents of water and suspended sediment concentrations of samples collected at the Sg Kurau inlet and in the lake. The relationship is a strong positive log-linear function observed between logTP and logSSC at Kurau River ($R^2 = 0.69$; Fig. 5) and in the lake (R^2=0.76, Fig. 6).

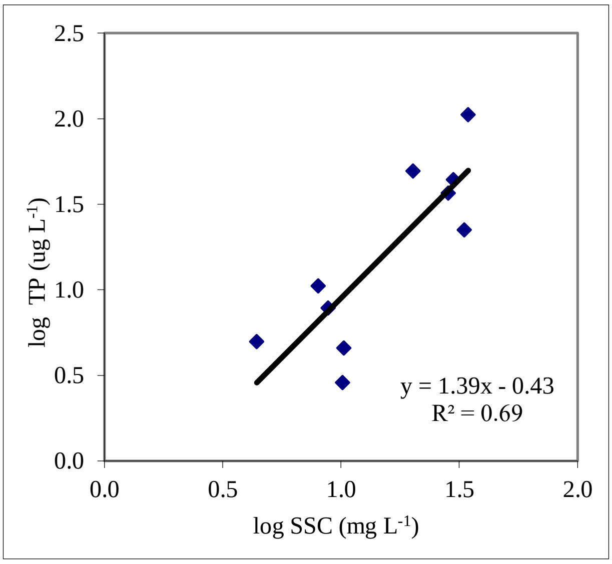

Fig. 5 Regression of log TP and log SSC at Kurau River

Table 2 Suspended sediment concentration (SSC), turbidity and Secchi disk depth values of BMR in 2007 and 2008

	2007		2008	
Parameter	Range	Mean ± StdDev	Range	Mean ± StdDev
SSC (mgL^{-1})	0.93–38.00	8.61±6.26	0.13–202.0	13.52±19.98
Turbidity (NTU)	6.33–31.73	12.40±5.25	5.88–64.10	22.92±15.95
Secchi disk depth (m)	0.3–1.85	0.85 ± 0.25	0.26–1.20	0.74 ± 0.21

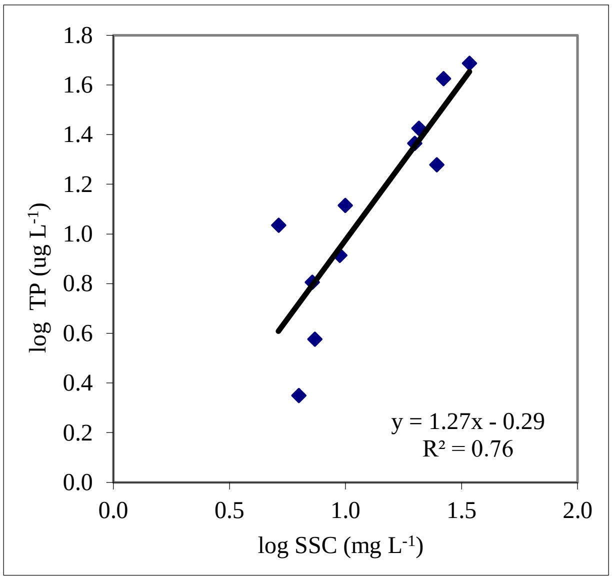

Fig. 6 Regression between log TP and log SSC in the lake

Trophic status

Table 3 shows the 3 TSI at 6 different sites of the lake. The average TSI (SD) was 64.12, which is indicative of an eutrophic status. The average SD transparency for the entire study period was 0.76m, with a minimum SD of sometime 0.3m after storms usually at the station near the Kurau river mouth. During clear water SD could reach a maximum depth of 1.0m. This average SD is very shallow, less than 1 m showing less penetration of light cause by many factors ranging from maybe colloidal organic matter or colour (Schindler, 1971), or turbidity from suspended inorganic particulates (Zettler and Carter, 1986) and phytoplankton (Ostrofsky and Rigler, 1987).

Table 3 Trophic status based on three indicators for six sites in Bukit Merah Reservoir

Sites	TSI (SD)	TSI (TP)	TSI (Chl-a)	Mean TSI
S1	66.21	46.85	50.28	54.45
S2	68.49	43.84	55.40	55.91
S3	61.46	42.15	52.18	51.93
S4	61.27	43.88	53.98	53.04
S5	63.38	44.75	54.82	54.32
S6	63.94	45.73	61.38	57.02
Mean TSI	64.12	44.53	54.67	54.44
Class	Eutrophic	Mesotrophic	Eutrophic	Eutrophic

Notes: TSI is Trophic Status Index;
SD is Secchi Disc Depth; TP is Total Phosphorus;
Chl-a is chlorophyll-a.

The lake was classified as mesotrophic based on TP (TSI = 44.5); but slightly eutrophic based on chlorophyll-a (TSI = 54.5). The average classification was however slightly eutrophic with the value of 54.44, as it slightly exceeds the maximum limit for a mesotrophic classification (see Table 3).

DISCUSSION

Sediment fluxes

The transport of suspended sediment derived from upstream sources affects the biogeochemical flux of downstream river systems (Meybeck, 1984). Into the studied reservoir most of the suspended sediment load came from Kurau River, which drains a very dynamic catchment with vast differences in land uses, which in turn caus significant erosion and sediment transport in the Kurau River catchment (see Table 1). Furthermore, due to its large size, the Kurau River catchment produced much higher river discharge in the wet months when most of the sediment is transported from the catchment into the reservoir.

Large amount (36%) of sediment is deposited in the BMR annually (see Table 1). The main contribution of sediment to the reservoir is from the Kurau River, where about 82% (12,900 t year^{-1}) of the total annual sediment input compared to the contribution from the north pool, which is about 18.4% (2,900 t year^{-1}). The sediment yield of the Kurau River is only about 39.8 t km^{-2} year$^{-1,}$ which is an underestimation because of the sampling frequency. However, it is comparable to other sediment yields in Malaysia, which are affected by mixed land use dominated by agriculture (see Table 4).

Large amount of sediment input to the BMR from Kurau River is related to the recent land use change where about 46% of land uses consists of oil palm and rubber plantation. This cause high erosion and sediment transport, especially during rainy seasons. The rate sedimentation in the lake were reportedly to increase from a rate of 0.36 mm year^{-1} (1995–2000) to 0.48 mm year^{-1} (2000–2005) (Ismail et al. 2010). Such results go in line with other evidence illustrating that sediment delivery can be increased from 5 to 10 fold following major human impact (Dearing and Jones, 2003). The high sediment discharge of the Kurau River also affecting the river and lake water turbidity and Secchi disk depth transparency, especially at the river mouth (station S3, S4 in Table 3). The increase in the sediment loading in aquatic systems in recent decades as demonstrated by the BMR (Table 1) is an example of many cases of anthropogenic impacts on aquatic ecosystems globally.

Total Phosphorus

The primary sources of new nutrients to lakes are terrestrial runoff and atmospheric input. With the exception of some of the great lakes, internal reservoirs in lakes are relatively small, and lakes are therefore very responsive to seasonal inputs (Guildford and Hecky, 2000). The TP input for BMR was about 19,300 t year^{-1}. This is probably related to the fact, that rubber, paddy and oil palm plantations cover 39% of the catchment area.

Table 4 Sediment yield of selected Malaysian catchments

Catchment	Area (km^2)	Sediment Yield ($t\ km^{-2}\ yr^{-1}$)	Source
A. Forested Catchments			
Bukit Berembun, Negri Sembilan	0.04	20	Baharuddin (1988)
Telom River, Cameron Highland	77	53	Shallow (1956)
Mupor River, Johor	21.8	41	Leigh and Low (1973)
Chuchuh River	0.96	58-72	Rahaman and Ismail (2006)
Air Terjun River (94% forest)	31.5	102	Ismail (2000)
B. Secondary Forests			
Tekam River	0.47	35	DID (1986)
Sipitang, Sabah	0.15	60	Malmer (1990)
C. Cleared or logged catchments			
Tekam River, Pahang	0.47	660	DID (1986)
Sipitang, Sabah	0.15	300	Malmer (1990)
Ulu Segama, Sabah	0.56	1600	Douglas et al (1992)
Berembun	0.13	189	Baharuddin (1988)
D. Urbanised catchments			
Relau River, Penang	8.9	3100	Ismail (1996)
Jinjang River, Selangor	10.3	1056	Balamurugan (1991)
Kelang River, Selangor	14.2	1480	Balamurugan (1991)
E. Mixed Land use			
Pelarit River (quarry, forest)	49.5	151-310	Rahaman and Ismail (2006)
Jarum River (urban, agriculture)	94.5	92-156	Rahaman and Ismail (2006)
Kurau River (agriculture, forest)	323	40	This study

The amount of TP retained in the lake was 36%, which is most likely absorbed to fine sediment. It suggests that large influxes of P into the lake may be held only temporarily in the reservoir, and subsequently it is released to growing plants and algae (Harter, 1968).

The high nutrient concentration recorded in Bukit Merah Reservoir could be explained by the concurrence of various diffuse sources including intense agricultural (rubber, oil palm and paddy) throughout the basin accounted for almost 59% of TP flux into BMR (see Table 1). Usually lake sediments act as a sink for phosphorus (Kaiserli et al., 2002). However, under certain conditions the sediment may become a phosphorus source that can support the trophic status of the lake system (Ramm and Scheps, 1997; Zhou et al., 2001). Not all of the phosphorus fractions, however, can be released from sediments into the overlying water and lead to lake eutrophication (Gonsiorczyk et al. 1998). Therefore, the phosphorus behaviour in lake sediments for promoting lake eutrophication can be more efficiently evaluated based on the examination of phosphorus geochemical distribution instead of the total phosphorus content (Kaiserli et al., 2002).

Trophic Status Index (TSI)

The lake was slightly mesotrophic based on TP but eutrophic based on chlorophyll-a and SD. Naumann (1932) classified mesotrophic water as water with moderate nutrient concentrations and therefore it has more biological productivity and the water may be lightly clouded by organic matter sediment suspended solids or algae, while eutrophic water is extremely rich in nutrient concentrations with high biological productivity.

The BMR lake water was also found to be slightly eutrophic, which is related to high productivity (see Table 3). The high sediment load had a significant influence on the clarity or transparency of water in the lake, especially near the Kurau river inlet and the inlet from North Pool. Secchi depth transparency is more strongly associated with the concentration of a particulate suspended matter than a dissolved organic matter (Wetzel, 2001). Thus, TSI (SD) is influenced by sediment from inlets and potentially by re-suspension of bottom sediment since the lake is shallow. The high sediment load causes significant influence on the clarity or transparency of water in the lake especially near the river inlet of Sg. Kurau river and Inlet from North Pool.

Chlorophyll has been significantly correlated with phytoplankton density (Nicholls and Hopkins, 1993). High chlorophyll concentrations are common in the Bukit Merah Reservoir, eutrophication is related to high productivity and nutrient such as nitrogen and phosphorus, which are well-known essential nutrients for algal productivity. N and P can promote excessive algal growth. The combination of nutrient additions coming from streams and rivers, and the recirculation of nutrients from the bottom sediments can considerably cause more productivity than the waters of open lakes (Stoermer, 1978).

Regarding the nutrient availability and recycling of phosphorus from the sediments, it has long been accepted that productivity in the reservoir is limited by phosphorus because of the extremely low concentrations present in the water column. It is also known that phosphorus is recycled into the aquatic system through sediment re-suspension events, dissolution and re-adsorption at the sediment and water interface (Heath, 1995). This is probably a factor of the heightened nutritional input that the Bukit Merah reservoir receives from point and non-point source pollution.

CONCLUSIONS

In conclusion, both sediment and TP loading into BMR were reasonably high at about 15,800 t year^{-1} and 19 t year^{-1}, respectively. These values were, however, underestimated due to the sampling programme that excluded storm samples. The main cause of reservoir sedimentation is the high sediment discharge from river inputs, especially from Kurau River, which has the largest catchment upstream of BMR. The high nutrient concentration recorded in BMR could be explained by the concurrence of various diffuse sources, including intense agricultural activity throughout the basin, as well as, the increasing development in the drainage basins. Most of the sediment is associated with erosion of the catchment areas affected by land clearing and agriculture, which cause the increase in the sediment and nutrients transported into the lake. In turn, this has caused a change in the water quality and the current state of the reservoir is slightly eutrophic with average TSI of 54.4. These data are critical in supporting future catchment management decisions for future improvement of the lake's trophic status.

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TOWARDS A CONTINUOUS INLAND EXCESS WATER FLOOD MONITORING SYSTEM BASED ON REMOTE SENSING DATA

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Abstract

Inland excess water (IEW) is a type of flood where large flat inland areas are covered with water during a period of several weeks to months. The monitoring of these floods is needed to understand the extent and direction of development of the inundations and to mitigate their damage to the agricultural sector and build up infrastructure. Since IEW affects large areas, remote sensing data and methods are promising technologies to map these floods. This study presents the first results of a system that can monitor inland excess water over a large area with sufficient detail at a high interval and in a timely matter. The methodology is developed in such a way that only freely available satellite imagery is required and a map with known water bodies is needed to train the method to identify inundations. Minimal human interference is needed to generate the IEW maps. We will present a method describing three parallel workflows, each generating separate maps. The maps are combined to one weekly IEW map. At this moment, the method is capable of generating IEW maps for a region of over 8000 km^2, but it will be extended to cover the whole Great Hungarian Plain, and in the future, it can be extended to any area where a training water map can be created.

Keywords: inland excess water, Sentinel 1, Sentinel 2, monitoring, flood, water management

INTRODUCTION

Temporary inundations of large parts of the flat areas on the Great Hungarian Plain cause serious financial, environmental and social problems. On the contrary to riverine and coastal floods, these floods occur when – due to limited runoff, infiltration and evaporation – the superfluous water remains on the surface, or at places where groundwater – flowing towards lower areas – appears on the surface by leakage through porous soil. In literature, the inundations are often identified as inland excess water (IEW), surface ponding, areal flood or surface water flood (Rakonczai et al., 2011; Szatmári and van Leeuwen, 2013). Three main reasons can be identified to study IEW. It is studied to (1) understand the interrelated factors and processes that cause the formation of inland excess water, (2) to determine the location and size of the inundations to be able to take operative measurements to mitigate and prevent further damage, and (3) to forecast the location, size and duration of future floods to develop preventive policies (van Leeuwen et al., 2016).

Four general approaches have been applied to study the development, extent and duration of IEW inundations. First, in Hungary, since the second half of the 20th century, at national scale the extent of IEW was measured by observations in the field. These observations are labour intensive and therefore expensive. They are error prone due to differences in observation and interpretation techniques and they are usually performed infrequently, so they give an overview of the maximum extent of the flood, but it is not possible to use them for monitoring purposes. The second approach uses geographic information systems to combine many factors related to the development of IEW, to create maps describing the vulnerability of areas to the inundations. These maps are normally made at regional scale, which is the scale of most of the input data (Pálfai, 2003; Bozán et al., 2005; Bozán et al., 2009; Pásztor et al., 2014). Vulnerability maps provide information on the general probability that somewhere IEW will occur, but do not give information about the actual occurrences, nor about the development of the phenomenon. The third approach is the application of complex distributed models to simulate the hydrological processes causing IEW. Since this technique requires large amounts of very detailed input data, it is only feasible to use it at a small area. Depending on the quality of the input data, the technique can provide accurate information on the occurrence, extent and progress of IEW. It may also be able to forecast where IEW may occur (van Leeuwen et al., 2016). The last approach to the problem of IEW is the use of remote sensing data. In the past 30 years, studies have been published using aerial photographs (Licskó et al., 1987; Rakonczai et al., 2001; van Leeuwen et al., 2012), multispectral satellite data (Csornai et al., 2000; Rakonczai et al., 2001; Mucsi and Henits, 2010) and hyperspectral data (Csendes and Mucsi, 2016). Also, some experiments have been executed using active satellite data (Csornai et al., 2000; Csekő, 2003; Gálya et al., 2016). The use of remote sensing techniques allows for the acquisition of data of medium (aerial photographs) to large areas (satellite data). Well understood processing techniques like classification and segmentation allow for the standardized processing of data and provide unified results over large areas. Common disadvantages of satellite data are their low temporal resolution and the limited availability of multispectral data due to bad atmospheric circumstances. Also, the resolution of non-commercial data was sometimes not suitable for IEW studies.

In 2014, as part of its Copernicus program, ESA started to launch the first satellites in its Sentinel Earth observation constellation (Malenovský et al., 2012). The data from the satellites is made publicly available free of charge and without restriction of use. With the formation of the Sentinel satellite constellations, to a large extent, the earlier disadvantages of satellite data can be overcome. For IEW monitoring, two types of satellites in the constellation are suitable. First, the Sentinel 1A and 1B satellites provide active remote sensing data with medium spatial resolution and a high temporal frequency. The active data is available under most weather conditions, and is therefore very suited for inland excess water monitoring. Second, Sentinel 2A and 2B provide multispectral data with a similarly high temporal and spatial resolution.

Contrary to earlier approaches, in this research, we developed a workflow that is capable of monitoring inland excess water on a weekly basis with sufficiently high resolution. The aim of the workflow is to produce IEW maps, that provide information on the location and extent of IEW for operational purposes, so operative measures can be initiated to mitigate and prevent further damage. The input data consists of a combination of Sentinel 1 radar images and Sentinel 2 or Landsat 8 multispectral images, complemented with a set of vector files providing a priori information about permanent water and other areas where inland excess water does not occur. All data is independently processed and combined at the end of the workflow to produce an integrated IEW map. For each IEW maintenance area, the relative coverage by inland excess water is calculated.

Many scientific publications have focused on causes of IEW, like soil characteristics (Barta, 2013; Gál and Farsang, 2013), land use (Barta et al., 2016), geomorphology (Benyhe and Kiss, 2012), or how they interrelate (e.g. Kozák, 2006; Rakonczai et al., 2011; Pásztor et al., 2014). Our approach concentrates on the continuous mapping of IEW for monitoring purposes and therefore factors related to the development of IEW are not taken into consideration.

STUDY AREA AND DATA

Study area

Due to its natural characteristics, inland excess water often occurs on the Great Hungarian Plain. Because of its low relief intensity combined with intensive or long periods of rainfall, mainly at the end of the winter, water does not run off to larger rivers nor infiltrates at a rate high enough to prevent it from remaining on the surface (Rakonczai et al. 2011). The southern region of the Great Hungarian Plain is maintained by the Lower-Tisza District Water Directorate and was selected as study area for this research (Fig. 1). It has a total area of almost 8200 km^2. The region is crossed by the Tisza and Maros rivers. Relief is limited to several meters of height difference and the lowest elevation in Hungary can also be found here. Based on its soil characteristics, the area can be divided in two parts; the western part has sandy soils, while the eastern part is covered with clay. The west is mildly sensitive to IEW according to the Palfai IEW Vulnerability map, while the east is moderately sensitive. Several disconnected areas are defined as highly vulnerable (Pálfai, 2003). The long-term average size of the area covered by the inundations in the study region is 10 800 ha per year. The largest area covered with IEW in recent times was 108 050 hectares in January 2000. The area is mainly agricultural, but there are also villages and some larger cities. The railroad and two highways have considerable influence on the development of inland excess water in the region (Barta et al., 2016).

Each of the used data sets covers the study area with one complete image or tile. The 175th ascending orbit of Sentinel 1 completely covers the area. Apart from a small strip in the west, the 34TDS Sentinel 2 tile covers the area, and the Landsat 8 WRS 187/28 covers the area except for a small area in the north. In this case study, the focus was to develop a method to generate inundation maps based on the individual images from different sources, therefore only the intersection of the footprints of the three satellite images was used to define the study area for this case study. This circumvents problems with mosaicking data of different acquisition times and sources.

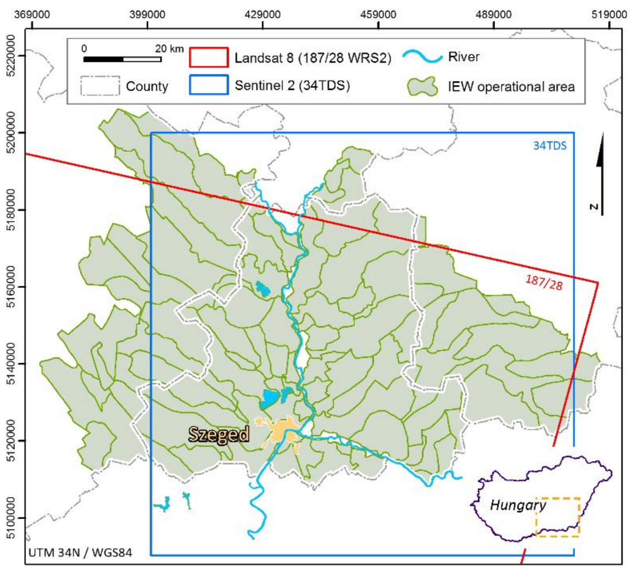

Fig. 1 The study area on the south part of the Great Hungarian Plain, showing the footprints of Sentinel 2 and Landsat 8 satellite imagery. Sentinel 1 covers the whole study area.

Data

Sentinel 1

The radar based part of the workflow uses data from the Sentinel 1A end Sentinel 1B satellites. The two satellites form a constellation that provides an image of the same area of Hungary about every third day, using identical instruments. Hungary is covered by 4 ascending and 4 descending paths (Fig. 2). In the presented workflow, we are using the Level-1 Ground Range Detected (GRD) product, that consists of focused SAR data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model. The phase information is lost. The product has approximately square resolution pixels and square pixel spacing with reduced speckle at the cost of reduced geometric resolution. Data was collected in the so-called Interferometric Wide (IW) swath mode and has a 250 km swath width and a pixel spacing of 10 x 10 meter (Malenovský et al., 2012). The data product comes with VV and VH polarization, which are both used in the workflow. Different objects in the terrain have different polarisation properties, therefor dual polarization images provide better options for object extraction. Sentinel 1 GRD IW data was used because it does not require further preprocessing, while it contains enough information to retrieve open water. The acquisition date of the analysed example image is 16 March 2016.

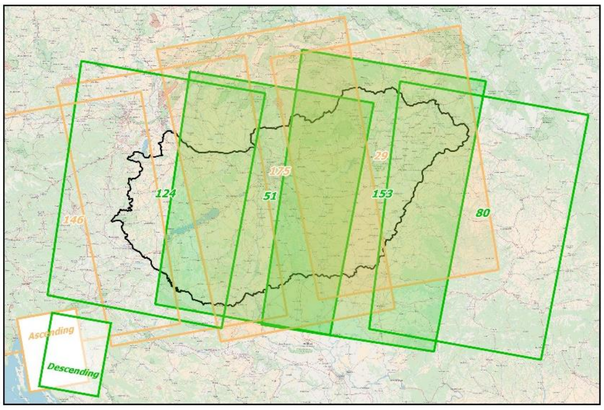

Fig. 2 Sentinel 1 paths covering Hungary

Sentinel 2

The ESA Copernicus program contains of two multispectral imaging satellites: Sentinel 2A and Sentinel 2B. At least once every 5 days, they provide high-resolution optical data in the visual, near infrared (NIR) and shortwave (SW) infrared spectral range for earth observation. Level 1C data products are tiled in 100x100 km tiles with 10 km overlap (Fig. 3) and store top-of-atmosphere reflectance values with UTM projection. Hungary is covered by 17 tiles in total. The applied visual and NIR bands have 10 meter spatial resolution, while the SW infrared bands have 20 meter spatial resolution. Data can be downloaded from Copernicus Open Access Hub in SAFE data package format. A cloud mask comes as metadata layer with every dataset. The study area is covered by the 34TDS tile. The acquisition date of the analysed example image is 21 March 2016.

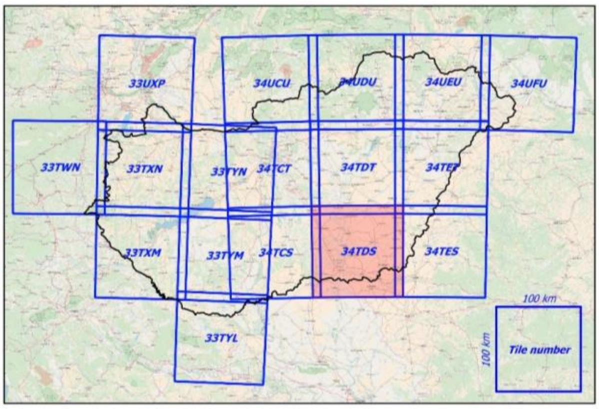

Fig. 3 Sentinel 2 tiles covering Hungary

Landsat

The Landsat OLI multispectral instrument acquires data in 9 spectral band between 0.43–2.4 µm with a temporal interval of 16 days. The 185x185 km images (Fig. 4) can be downloaded free of charge within 24 hours after their acquisition. The Landsat Surface Reflectance High Level Data Product “Surface Reflectance” L8SR data product provides 30 meter atmospherically corrected surface reflectance values for the first 7 spectral bands (USGS 2017). The data product also comes with a cloud mask identifying areas in the image that are not suitable for processing. The acquisition date of the analysed example image is 17 March 2016.

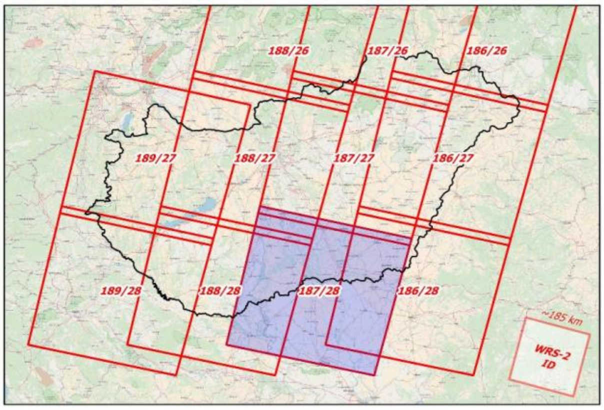

Fig. 4 Landsat 8 WRS paths covering Hungary

Auxiliary data

The active and passive remote sensing based workflows require a layer identifying open water. This file is necessary for the determination of the spectral thresholds and as training areas for the classification. Open water was extracted from the CORINE land cover 1:50 000 and 1:100 000 databases and the 20 meter Pan-European High Resolution Layers permanent water bodies maps (Copernicus HRL) (Büttner et al., 2014) and are stored in a vector layer. The open water file was updated by visually inspecting and editing differences using GeoEye imagery from 2014 - 2015 with a spatial resolution between 0.41 and 1.65 meter available in Google Earth. In this way, vegetation along the river banks, shadows and infrastructure in the water were removed from the open water layer.

Furthermore, urban areas, rural anthropogenic surfaces, paved roads and railroads were extracted from the CORINE databases and OpenStreetMap (OSM). These objects were stored in a mask layer, identifying areas that were excluded from the inland excess water calculations. The mask layer was further expanded with natural or man-made water bodies and wetlands. The floodplain between levees was also included in the mask.

The areas defined as cloud or cloud shadow in the Sentinel 2 and Landsat 8 cloud masks were not taken into considerations during the IEW calculations.

METHODS

The method proposed in this research is divided in workflows based on the type of input data. The active satellite data is used in a process where a threshold is defined to separate pixels with water and without water. The passive data sets are processed in two different ways. The first way uses unsupervised classification combined with an automatic method to select the water classes from the classification results. The second way is the calculation of a water index based on the ratios of bands. The following section describes each processing method in detail.

Downloading satellite data

All satellite data used in the workflow can be downloaded without restrictions and without charge. The Sentinel 1 and Sentinel 2 datasets can be downloaded manually from Copernicus Open Access Hub or in an automated way from API Hub using OpenSearch API and OpenData API. The downloaded product level is Level 1 GRD for Sentinel 1 and Level 1C for Sentinel 2 satellites. Raw Landsat 8 data can be downloaded from the USGS. To acquire Landsat surface reflectance data an on-demand request is required. This takes several days and may not always be suitable for operational purposes.

Preprocessing of satellite data and extraction of water surfaces

Radar data

A disadvantage of radar data is the complex geometric and radiometric processing required to extract useful information from the images. To start the extraction of the waterbodies, the Sentinel 1 data first needs to be radiometrically calibrated, a speckle filter needs to be applied to reduce the noise in the image, then the deformations due to the side looking geometry of the sensor and the terrain must be corrected, and finally a correction of the local incidence angle needs to be applied. After these initial steps, the data is geometrically and radiometrically corrected and transformed to a geometry that can be combined with the other data sets. The unit of the processed data is decibel (db).

In a geographic information system, the next steps are executed. First, the vector mask indicating the known open water is used to extract the statistics of water from the VV and VH radar images. The two sets of statistics are then used to extract similar pixels in the images, using a threshold method. The threshold method simply extracts pixels below a certain value (the maximum value in the reference statistics), presuming that the radar response of water is considerably lower than the response of other pixels. Some correction must be applied due to the statistics of outliers (which remained after the speckle filtering). In the final step of the radar processing workflow, those areas that are known as permanent water bodies or other none IEW areas are extracted from the map. The final map is a binary map with two classes: inland excess water inundations and other land cover.

Optical data

The downloaded Sentinel 2 and Landsat 8 datasets must be preprocessed before the interpretation of surface water patches is possible. The preprocessing workflow for optical data includes atmospheric correction which provides surface reflectance values; resampling of bands with a different pixel size to a common resolution; and spatial and spectral subsetting of the dataset to the study area and to the required spectral bands. To mask unusable areas covered by clouds or their shadow, auxiliary datasets have to be processed.

Unsupervised classification and class selection on optical data

The result of the applied classification algorithm must be evaluated using statistical methods to select the classes representing inundations. For this purpose, reference statistics must be created from training areas permanently or temporally covered by water. From the average of the reflectance values of the training pixels in each spectral band, a reference spectrum can be defined. After getting the reference spectra, the whole preprocessed image is classified. To support operative decisions an unsupervised clustering algorithm was selected to create a classified raster map and a signature file. The latter contains the statistical parameters - like minimum, maximum, mean, standard deviation in each band, and covariance matrix - of each cluster. In the last step, the spectral similarity between the reference class defined by the training areas and the individual clusters is evaluated. There are many different statistical methods to calculate spectral similarity or spectral separability between cluster of pixels in the n-D spectral space. Some of them, like for example Euclidean Distance use only the class mean values to measure n-D distances. Advanced calculations, like Divergence, Transformed Divergence and Jeffries-Matusita Distance (Swain and Davis, 1978), Bhattacharyya Distance (B-distance) (Jensen, 1986) use the covariance matrix beside the mean vector. In this research, the class similarity to the reference is calculated by the n-D Spectral Angle Difference method, which is not affected by the solar illumination factor and requires only the class means (Kruse et al., 1993). The result classes are rated based on this difference: a smaller angle means higher similarity and vice versa. Classes with the lowest spectral angle differences represent permanent water or inundations.

Spectral indices

In the infrared part of the electromagnetic spectrum, water is absorbed in the SWIR band, while reflected in the visible range. The Modified Normalized Differential Water Index (MNDWI, Xu 2005) uses the green and shortwave infrared bands from Sentinel 2 and Landsat 8 to extract open water according to the following expression:

$$\mathrm{MNDWI} = \frac{\rho_{green} - \rho_{SWIR}}{\rho_{green} + \rho_{SWIR}} \quad \text{(Eq. 1)}$$

where ρ_{green} is band 3 for Sentinel 2 and Landsat 8 and ρ_{SWIR} is band 11 for Sentinel 2 and band 6 for Landsat 8

If the water content decreases, the reflectance in SWIR increases, resulting in a reduced value of the MNDWI index. Based on the MNDWI values calculated from the permanent open water zones in the open water mask, empirically threshold values were defined for the two indicators:

MNDWI (L8) >= -0,25 and MNDWI (S2) >= -0,35

Using these thresholds, a binary map was derived with two classes: inland excess water inundations and other land cover.

Integration

The maps that are created based on different input data and using different processing methods need to be integrated to one inland excess water map. For this case study, only images that cover the same area have been used. In the operative situation, this is not realistic since one satellite image does not cover the complete Great Hungarian Plain, and neighbouring images are collected on different dates. This results in a complex situation where output maps from different sources and different acquisition dates will need to be mosaiced.

RESULTS

In 2016, no exceptionally large amount of inland excess water occurred, but from half of February until half of March, some IEW developed in the study area. Using the described method IEW maps were created for this period (week 6 - week 11, 6 February - 18 March). As an example, figures 5 and 6 show the results for week 11 (13 – 19 March). In this week, all three sources of satellite data, Sentinel 1, Sentinel 2 and Landsat 8 were available. Figure 5 shows the results of the active data processing workflow, the unsupervised classification and the index based IEW identifications. Obviously, every method provides slightly different results. The largest difference is visible in the southeast quadrant where clouds and cloud shadows disturb the unsupervised classification result.

When the three workflows are combined, one IEW map is created. The different input maps are weighted to define the areas with the highest confidence that IEW indeed occurred at the indicated pixels. Figure 6 shows only those areas where inundations were identified using all three methods. Using data from 3 different sources (Sentinel 1, Sentinel 2 and Landsat 8) and using three different processing techniques (thresholding, unsupervised classification and indexing) results in maximum 5 separate IEW maps. If all 5 maps indicate IEW for a certain pixel, the change that IEW was indeed happening at that pixel is larger than when only one method identified IEW at that particular pixel. Combining the different maps and counting the amount of positive IEW identifications gives an indication for the confidence of IEW.

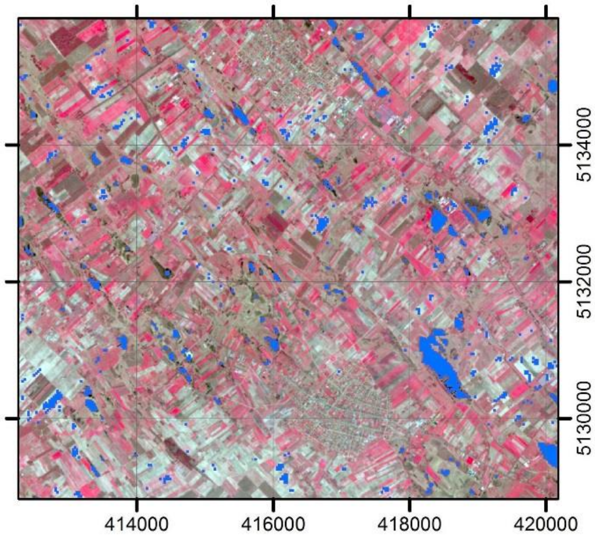

Fig. 6 The integrated inland excess water map based on three different sources/methods for week 11, 2016. Blue indicates water surface

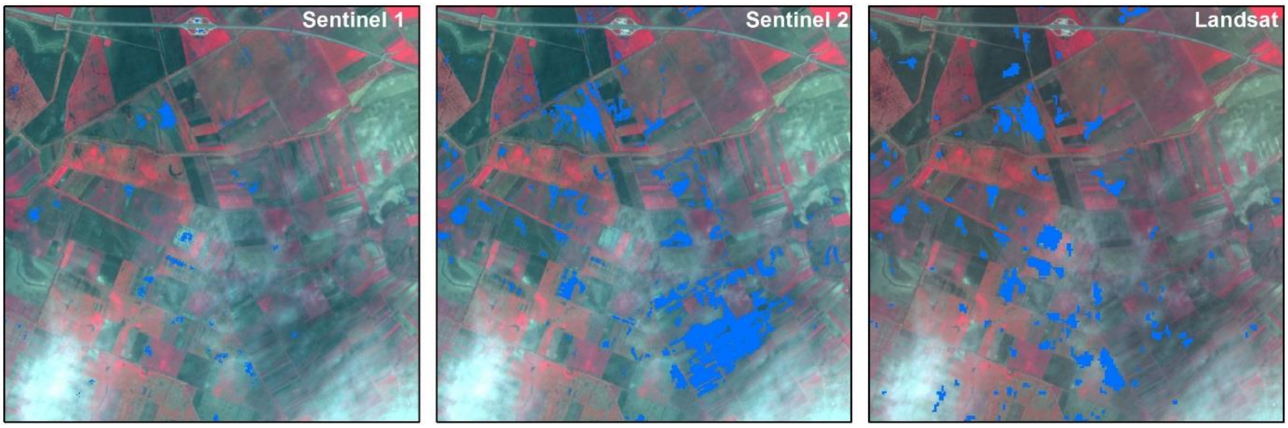

Fig. 5 Sentinel 2 false colour composite (RGB 843) covered with the results of the three separate processing workflows

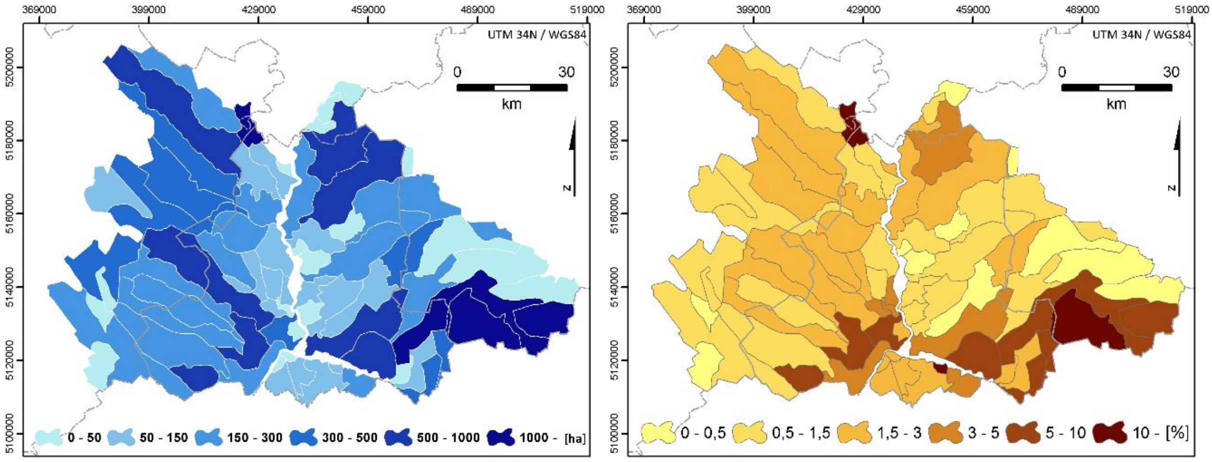

Fig. 7 Result maps showing the absolute (in hectare within the area) and relative (as percentage of the area) distribution of inland excess water per maintenance area in the Lower-Tisza District Water Directorate region

Based on the combined IEW maps, thematic maps are created indicating the area and ratio of IEW per IEW maintenance areas (Fig. 7). In operational circumstances, these maps can be used to determine spatial distribution of the severity of IEW throughout the region.

DISCUSSION

The presented method consists of three different workflows. Each workflow is aimed to create separate inland excess water maps based on procedures that can be used in an operational environment. Since the workflow has to be executed within a few days of the acquisition of the data, sometimes the proposed methods are a compromise between speed and accuracy. Deliberately, methods are developed that can be automated, so human influence is reduced to a minimum. This also means that there is no possibility for fine tuning of the method to specific situations. This may reduce the accuracy of the method.

The threshold method applied to the active data is a relatively simple method, that is easy to automate. In operative circumstances it provides reasonable results, but other techniques might be more suitable when performing detailed IEW studies at local scales. The speckle filtering is only based on a single image; therefore, it is not perfect and leaves unwanted spikes in the data which reduce the quality of the extracted statistics. Improvements in the speckle filtering should be investigated to improve the method. Another promising method is radar based change detection. This method might be useful to identify false positives resulting from the threshold method.

Inland excess water normally occurs during periods of bad weather and clouds. Our method uses multispectral satellite data to complement the active data, but the use of the multispectral data is often hampered due to clouds. Using a cloud mask allows us to use those parts of the multispectral data that are not covered by clouds. In the current method, standard cloud masks are used that come with the data products. These masks sometimes do not incorporate all clouds in the images and therefore sometimes lead to misclassifications. Improvements of the cloud mask can improve the multispectral data based inundation maps.

The result of earlier IEW research is often a single map that contains 4 classes: dry land, open water, saturated soil and vegetation in water. The presented workflow ignores the last two categories and therefore probably underestimates the total amount of inland excess water in the region. The determination of the last two categories requires additional data, which changes rapidly in space and time, and this makes it difficult, if not impossible to incorporate them in an automated operative environment, that produces timely, weekly inundation maps for large areas.

The intersection of the three data sources was used to determine the study area for this case study. Of course, in operational circumstances the complete Great Hungarian Plain needs to be used in the calculations. This increases the complexity of the method.

The method could be enhanced using other a priori data sets. The sandy soils show an overestimate of IEW inundations. This problem was reduced by applying a different threshold to the radar data, based on the soil type. Also, other errors or inconsistencies could be reduced by adding information on e.g. land cover or soil type and by building up a database of landcover dependent threshold values.

The proposed method can generate timely IEW maps for large areas. Independent cross validation of these maps is difficult because they cover large areas and other reliable data is not available. Visual inspection of the results using high resolution imagery of small areas indicate that the method identifies inundations at the proper locations. A larger validation campaign based on high resolution aerial photographs of large areas is needed and planned.

CONCLUSION

Earlier approaches to mapping inland excess water were based on field measurements or aerial or satellite remote sensing data for a specific date. We present a method that is capable of continuously identifying inland excess water over large areas for operative purposes. It shows that combining the most recent active and passive data sources that are available at a very high temporal resolution provide new opportunities and challenges. The presented method provides maps that can be used by the Hungarian water directorates to mitigate damage caused by inland excess water, but there are still quite some problems and possibilities for improvements. More scientific research is needed to improve the determination of the threshold for the active data processing workflow and to reduce the number of false positives. Also cloud masking of the multispectral data can be improved to better select data suitable for processing. Finally, methods for mosaicking the different data from different acquisition dates within the operational workflow need to be developed.

ESA's Sentinel satellites will continue to provide base data to derive IEW maps, which allow for the development of a monitoring database. This database can be used to calculate frequency maps which indicate the vulnerability of an area to inland excess water.

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LANDSCAPE FUNCTION ANALYSIS AS A BASE OF RURAL DEVELOPMENT STRATEGIES

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Abstract

Research on ecosystem services and landscape functions are highly important in landscape ecology, landscape planning and open space design. The terms of ecosystem service and landscape function have been evolved parallel to each other in the scientific literature but have different focus. The term of landscape functions evolved from the scientific field of landscape ecology; it reflects the goods and services provided by regions, landscapes where the cultural, economic factors are important as well. As a framework assessment method with additional economic assessment, a landscape function analysis could be an additional tool of rural development, as it gives a complex analysis of multiple aspects, thus it is highly appropriate to explore, analyze the potentials, resources and limits of landscapes and land use systems. In the current research a landscape function analysis was compared with the rural development strategies in Hungarian micro-regions. We focused on the level of landscape functions and the objectives of the rural development strategies of the study areas. The local development strategies do not focus on territorial differences nor potentials evolving from natural, cultural resources or local constrains. The only exception is tourism development, where in some cases there is a holistic spatial approach which intends to develop the region as a whole.

Keywords: landscape functions, rural development, micro-regions of Csorna, Pásztó, Gönc

INTRODUCTION

The terms of ecosystem services and landscape functions are very popular in landscape ecology research, landscape planning and open space design. Since decades experts realized that the welfare of the society depend on the interactions with nature. The growing threat on our natural resources fostered researches on ecosystem services or landscape functions.

The concepts of ecosystem services and landscape functions have similar meaning but different focus. These terms have been evolved parallel to each other in the literature. For the first time Ehrlich and Ehrilch (1981) used the term of ecosystem services and later Costanza et al. (1997) dealt with the economic assessment of ecosystem services. The most important turning point was the publication of the results of the international research program Millennium Ecosystem Assessment supported by the UN, which remained the most comprehensive and complete program among those which have emerged in the field of ecosystem services (MEA, 2005). The research program focused on the relation between social welfare and ecosystem services. Those goods, services and spiritual, aesthetic values provided by nature as ecosystem services were considered which are used directly or indirectly by the human society (Costanza et al., 1997; de Groot et al, 2002). The landscape functions usually refer to the goods and services provided by regions, landscapes, when researchers analyze next to the environmental issues the infrastructural, cultural and economic characteristics of land use systems as well (Bastian, 1997; Hermann et. al,. 2004). Schößer et al. (2010) compares the similarities and differences of the three concepts of ecosystem services. The goods and services provided by landscapes can be distinguished by different methods, but usually these values are divided into three major groups: production/economic, ecologic/environmental (cultural, aesthetic, educational etc.) goods and services. De Groot and Hein (2007) distinguished the carrier functions in the frames of production functions providing space and suitable substrate for settlements and cultivation. In the model of landscape functions Brandt and Vejre (2004) distinguished land use functions referring to material processes connected with land use. Lamarque et al. (2011) highlights the fact that a clear demarcation between landscape functions and land use functions is not possible.

What is the relation of landscape services and rural development? Several researches focus on the multifuncinality of the landscape. The research of Willemen et al (2010) underlined the trend that at multifunctional locations the total provided goods and services by the landscape were higher than at monofunctional sites and similarly de Groot and Braat (2012) explored the relation between land use intensity and the level of ecosystem services highlighting the fact that extensive land use systems provide wider range and higher level of services.

Several researches (MEA, 2005; de Groot and Hein 2007; Willemen et al., 2010; Norgaard, 2010 etc.) have clearly defined the correlation between social welfare and ecosystem services/landscape functions, but especially in case of quality of life in rural areas we consider the wide range and complexity of landscape services extremely important. Land use conflicts occur in such cases when a dominant land use /landscape function hinder the harmonious functioning of other functions mostly regulation, habitat or cultural functions.

Herman et al. (2014) emphasize the spatial analysis of landscape functions in order to reach well founded landscape development decisions. In spite of the vast research, mapping the term of landscape functions has not been introduced into the landscape management neither in practice of rural development (Norgaard, 2010). But also Norgaard is the one who reminds us for the most important shortages of ecosystem service analysis which is that they are simplifying the real circumstances and cannot consider the impacts of human activities. That is why it is extremely important to consider the complexity and synergies of our ecologic and social systems.

The multifunctional agriculture, which represents a similar approach to landscape functions, highlights the social, cultural and ecologic role of agriculture as well (EEC, 1992; Ángyán and Menyhért, 2004). In case of rural regions of extensive use and dominantly of natural land cover we can consider ecosystem services as landscape functions since the focus is here on goods and services provided by nature and self-sustaining processes (Konkoly-Gyuró, 2011).

In our research we focus on rural development because its focus is more the locality, local communities, ecology and landscape values, while regional development highlights the importance of economic, technologic development. The Cork Declaration emphasizes the multidisciplinary character of rural development and complex, integrated, multisectoral approaches and their local focus (EC, 1996.). The EU Common Agricultural policy and the former experiences collected in regional development form rural policy in Hungary. Because of the financial shortages the tools of the EU rural development policy are the most important determining factors in this field in Hungary. The New Hungary Rural Development Programme forms the main priorities of agricultural and rural development. The rural development programs are realized mostly in the frames of LEADER program. The 96 Local Action groups try to mobilize local stakeholders and realize multisectoral development programs based on local strategies. The effectiveness of rural development depends on the depth of analysis of rural development strategies, whether the strategies consider the landscape conditions in reality, and react on the real values and conflicts. Our research focused on the following objectives:

- to analyze of the landscape-ecologic and economic characteristics of selected micro-regions through landscape function assessment method;
- to compare the results of landscape function assessment and the rural development strategies of the study areas.

STUDY AREAS

As study areas three rural micro-regions were allocated situated in different parts of Hungary: micro-regions of Csorna, Pásztó and Gönc (Fig. 1). These micro-regions are part of the new administrative system elaborated in 2011, they are administrative units (group of 27-33 settlements) which in size are similar to the statistic units of LAU1 level. All study areas are of rural character, of different landscape conditions and can be considered as peripheries.

Micro-region of Csorna

Micro-region of Csorna is situated in Kisalföld, in Region of Western Transdanubia which is the second most developed region of Hungary (% of the EU-28 average, EU-28 = 100, Central Hungarian Region - 105,45; Western Transdanubian Region – 74,53). But the development potential of Csorna lags behind the neighboring regional centers (Győr, Sopron, Mosonmagyaróvár). The micro-region consists mostly of villages of landscape of Hanság and Rábaköz. The settlement structure is characterized by small villages, 72% of the settlements have less than 1000 inhabitants, and just the center of the micro-region has slightly more than 10 000 inhabitants. Rábaköz has been an intensively cultivated landscape since centuries while in the North because of the vast marshland of Hanság large areas remained untouched. During 19^{th} and 20^{th} century drastic landscape changes took place because of the intensive drainage works. The remained moors, lakes, wet habitats, meadows of Hanság are the most important ecologic values of the region. The river Rába with its riparian forests mean a natural border in the South. The Rábaköz Rural Development Association holds the majority of the settlements together.

Micro-region of Pásztó

Micro-region of Pásztó is situated in county Nógrád, at the feet of mountain Mátra and the undulating landscape of Cserhát, relatively far from the major transportation corridors and the busy cities. The region similarly to Csorna can be considered as an inner periphery, characterized by small villages. Its center, Pásztó is located on the peripheries of the micro-region and the county, on the riverbanks of Zagyva. The city of Pásztó still in the medieval ages has been a busy cultural and economic center, transportation node but after the Ottoman occupation it couldn't regain its former significance. The fruit production, local vines, and the products of the water mills couldn't compete with the industrialization of the neighboring cities. Even the relocation of the major transportation corridors fostered this decline. The formerly important mines were closed. Beside these negative processes the growing importance of tourism can be seen in the region. The diverse landscape resources, the 'Palóc'

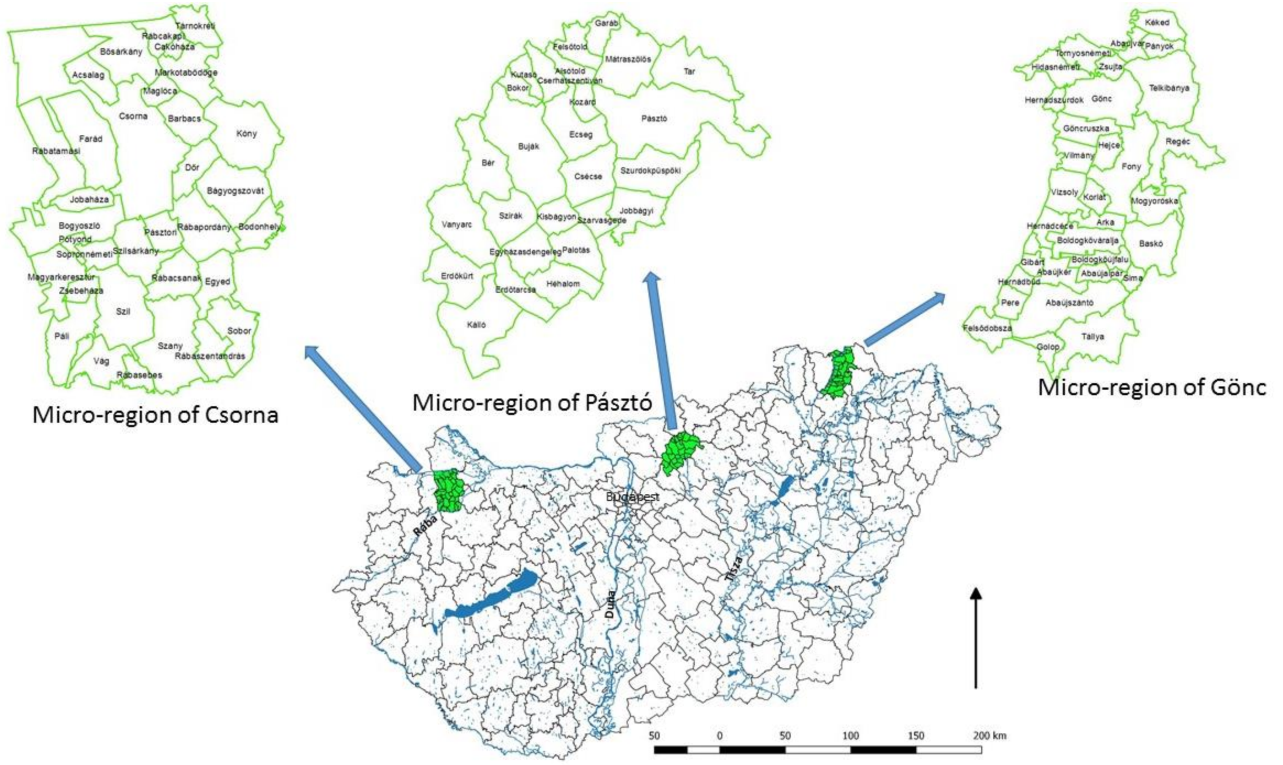

Fig. 1 The location of the study areas, the micro-regions of Csorna, Pásztó and Gönc

cultural heritage, the Nature Park of Cserhát and Geopark of Nógrád provide the base for the tourism and economy of the region. The mountains of Mátra and Cserhát surround the region offering picturesque landscape scenery, the cultural heritage of the villages are mostly of local, regional significance (Fig. 2). The majority of the settlements of the micro-region, with the exception of one single settlement belong to the Cserhátalja Local Action Group.

Micro-region of Gönc

Micro-region of Gönc is one of the most disadvantaged regions of Hungary in spite of the rich natural and cultural values. The studied region is located along the Slovakian border. From its 32 settlements two are towns (Gönc and Abaújszántó), 19 settlements have less than 1000 inhabitants. All the most important social and economic indicators show the unfavorable situation of the micro-region. In contrast, Gönc is rich in cultural heritage as the remnants of the old settlement structure the Hussite House in Gönc, or the castle in Boldogkő (Fig. 3 a, c). The Eastern-Southern Slovakian regional centre, Košice with its 300 000 population has a remarkable influence on the neighboring Hungarian areas as well especially after the opening of Schengen boarders. The Slovakian center is much closer to Gönc than Miskolc, the county seat. The recent connections have traditions since previously the region was called as "pantry of Košice". The settlement and infrastructure network of the micro-region have been formed by geographic conditions. The main transportation corridor of the region is stretching parallel to river Hernád (road Nr 3.). The majority of the smaller settlements are dead end villages. The Abaúj Leader Association (Local Action Group) holds 81 settlements together, and the majority of the micro-region of Gönc.

METHODS

The conditions and differences in and among the study areas were explored by landscape function analysis using landscape indicators. Our assessment is mostly based on data of the Hungarian Statistical Office and the Corine CLC database 2012 and the system of TEIR (National Information Database of Spatial Planning). Agricultural production and forestry, nature protection and habitat value based on naturalness, furthermore the cultural heritage were assessed. To investigate agricultural potential the ratio of arable land, ratio of fruit and grape plantations and forests were calculated. Almost half of our country's territory (48%) is arable land, thus we consider high intensity of cultivation in case the ratio of arable land is higher than 60 %, medium 40%-59% and low in case of lower values than 39% considering the ratio of arable land.

To characterize habitat value, the ratio of natural/semi-natural land cover forms and the ratio of protected areas were considered. We assessed the ratio of natural or semi-natural Corine land cover forms using the following Corine CLC types: land principally occupied by agriculture with significant areas of natural vegetation, natural grassland, moors and heathlands, Sclerophyllous vegetation, transitional woodland scrub, broad-leaved forests, mixed forests, inland marshes, peat bogs, stream courses, water bodies.

Fig. 2 Landscape and cultural values in micro-region Pásztó (Photos made by E. Dancsokné Fóris) a, The picturesque mountain line of Cserhát; b, Panorama of Mátraszőlős with mountain Mátra in the background; c, View of Tar

Fig. 3 Landscape and cultural values in micro-region Gönc (Photos made by I. Valánszki) a, Hussite House in Gönc; b, panoramic view of river Hernád; c, Boldogkő Castle

To assess ecologic value, the ratio of protected areas was calculated. If we consider nature and landscape protection, there are several levels and types of protection in Hungary. Beside the nature protection categories (there are 10 national parks, 36 landscape protection areas, 147 nature conservation areas in Hungary) there are Natura 2000 areas (European Union's level of protection) and the National Ecologic Network. The National Ecologic Network represents the widest type of landscape protection in Hungary, as this category is elaborated for spatial planning and includes all types of nature protection areas (Natura 2000 and national park areas as well) and other officially not protected but all the ecologically valuable areas. The National Ecologic Network as a regulation zone is available in the National Spatial Plan and in all the master plans of the settlements. To avoid the duplication and overlapping of different protection types we focused our assessment on the National Ecologic Network. In the frames of the National Ecologic Network three categories are distinguished: core areas, buffer zones and ecologic corridors. The percentage values of naturalness and protected areas were divided by 10 to get a scale between 1 and 10 to help the multi-aspect comparison between the study areas.

The evaluation of the beauty of the landscape is highly complex and sometimes because of its subjective judgment it is really difficult to find indicators. In order to avoid subjectivity, landscape beauty was related to naturalness (proportion of natural/semi-natural land cover forms) and as a weighing factor we considered the number and significance of cultural heritage/monuments based on the database of TEIR. The value of cultural heritage was calculated by the monument density per settlements and according to the significance we weighted the values. To get the final value of landscape aesthetics we summarized the values of naturalness and cultural heritage and calculated their average.

We assessed touristic and recreational values (number of guest nights, commercial accommodations) using the database of the Hungarian Statistical Office (2014). The data describing tourism potential varies on different scales, so to be able to summarize them and compare them on the level of settlements and micro-regions the data on a scale of 10 were projected and average value of data of number of guests and number of commercial accommodations were taken.

The economic value and availability are important factors in the welfare of local inhabitants. To be able to compare the regions the data on a scale of 10 were projected. We evaluated the economic value by domestic income indicator (Hungarian Statistical Office, 2015).

In the second phase of our research project the objectives and tools of the rural development strategies of our study regions were analyzed. We assessed how the strategies reacted or were adjusted to the local levels of landscape functions or ecosystem services.

RESULTS AND DISCUSSION

The landscape function analysis revealed the conflicts, limits of landscape resources and where certain landscape functions can be considered lower than the appropriate level.

Ecologic and habitat values

There are large differences in micro-region Csorna considering the ecologic values. We considered all types of nature protection areas including Natura 2000, national park and the National Ecologic Network but to avoid duplication in the comparison analysis we focused on the National Ecologic Network. In the Northern part of micro-region of Csorna, in Hanság high ratio of nature protection areas can be found. Hanság is part of the National

Park Fertő-Hanság, with Natura 2000 and Ramsar areas (proportion of Natura 2000 areas: 54% Tárnokréti, 36% Barbacs, 33% Maglóca, 33% Csorna) meanwhile Rábaköz consists of mostly intensively cultivated arable land (Fig. 4) and landscape protection is represented just by the parts National Ecologic Network, mostly as pastures and the riparian forests along river Rába. The lowest value among the study areas, 25% of the micro-region is part National Ecologic Network.

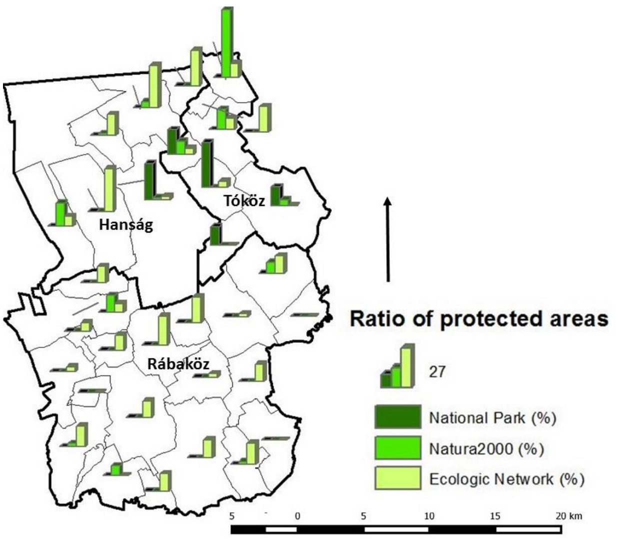

Fig.4 Ratio of nature protection areas in settlements of micro-region of Csorna with two characteristic landscape parts of Rábaköz and Hanság, Tóköz

Even micro-region of Pásztó can be considered inhomogeneous but with higher ratio of landscape protection areas, 47% of its total area is part of the National Ecologic Network. The Landscape Protection Area of Eastern Cserhát (Eastern part) and Landscape Protection Area Mátra (Northern part) are divided by intensive cultivated land and busy transportation corridors along river Zagyva. There are a few settlements where almost the whole territory is part of the National Ecologic Network (Felsőtold, Garáb, Cserhátszentiván).

In micro-region of Gönc Landscape Protection Area of Zemplén Mountains with a wider zone of Natura 2000 areas and protected areas along river Hernád (almost 80% of the micro-region is designated Natura 2000) are the most important nature protection areas. Among the study areas here the total percentage of the National Ecologic Network is the highest: 80%. But the connection between the core areas is insufficient, missing.

The proportion of natural and semi-natural land cover forms (naturalness values in Fig. 5.) is in case of micro-region Csorna the lowest 20%, in Pásztó 46% and the highest value can be found in Gönc micro-region 62%.

Landscape aesthetics

Landscape aesthetics was assessed based on the naturalness values and the number and significance of cultural heritage (database of national monuments TEIR database). If we consider the number of monuments (data base of TEIR) we find similar values in the study areas (micro-region of Csorna 66, micro-region of Pásztó 58, micro-region of Gönc 57, the density is ap. the same 2 per settlements), but in Csorna and Pásztó with a few exceptions the cultural heritage is mostly of local significance. In micro-region Csorna the most significant cultural value is the Norbertine Abbay. The villages are rich in architectural values but these are mostly of local significance. The indicators of landscape aesthetics reveal great differences in the micro-region. The majority of Rábaköz (the Southern part of the region) can be described as intensive arable land with large fields while Hanság, Tóköz are more diverse landscapes with higher proportion of natural vegetation or cultivated areas of lower intensity. As Csorna is situated in a plain, the diversity of different land use forms is highly intensive from point of view of aesthetics, the large fields of Rábaköz create a monotonous landscape.

Micro-region Pásztó has rich, living Palóc cultural heritage. The Palóc cultural trail connects the cultural, architectural values of the villages. The remnants of the former mediaeval city of Pásztó are still unknown for the greater public. Dense network of tourist trails connects the natural values of Nature Park Cserhát, Landscape Protection Area of Mátra and the Geopark. Hiking, eco-tourism and rural tourism are significant in the region.

In micro-region of Gönc the most important cultural and architectural values can be found in Gönc, Boldogkőváralja, Vizsoly and Tállya. The castle of Boldogkő or Regéc are remarkable landmarks with the

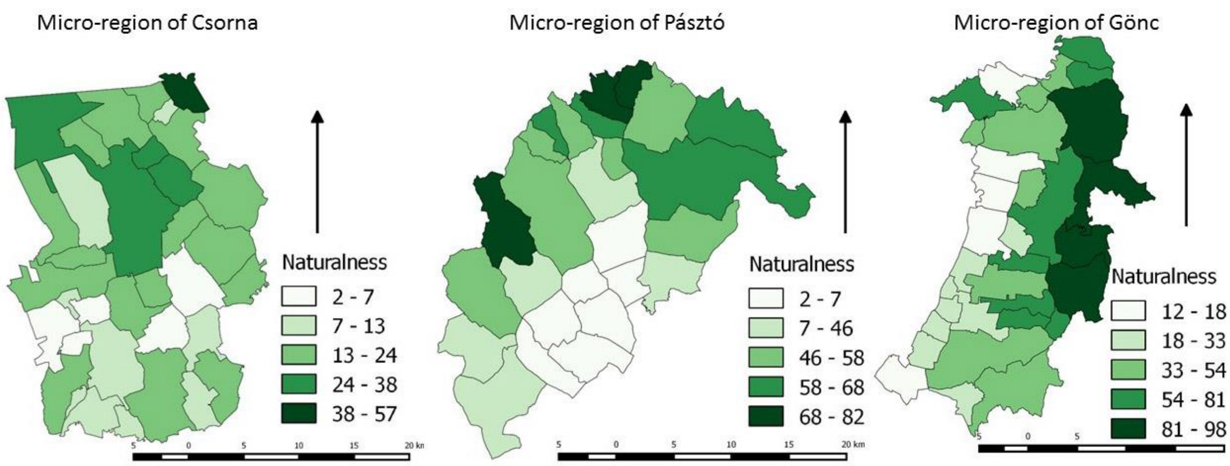

Fig. 5 Ratio of natural, semi-natural land cover form based on Corine Land Cover 2012 data

natural environment creating a highly attractive scenery. There are several values of national importance as Chuch of Vizsoly, Bible Museum of Gönc, castles of Boldogkővár and Regéc, wine production related heritage in Tállya and Abaújszántó. The traditional wine yards in the Southern settlements which are part of World Heritage Site Tokaj Wine region represent also unique landscape values. Values of less significance as rural churches, mansions can be found in all settlements. Because of the differences in significance of the cultural heritage we tripled the value of micro-region of Gönc (micro-region of Csorna: 2,1; micro-region of Pásztó 2,2; micro-region of Gönc: 5,7). According to the summarized and average values of naturalness and cultural heritage Gönc has outstanding values (micro-region of Csorna: 2,3; micro-region of Pásztó 3,4; micro-region of Gönc: 7).

Agriculture and forestry

In micro-region Csorna agriculture is still an important base of the local economy, unfortunately the volume of the former flourishing vegetable and fruit production dropped below the national average since 1990. Especially vegetable production was remarkable during the 1980's and the 1990's the cucumber was called as the "gold of Rábaköz". Rather the arable land became dominant, especially in Rábaköz the ratio of arable land is extremely high in several settlements (Cakóháza 86%, Egyed 84%, Rábapordány 88%, Rábacsanak 90%). The arable farming has less added value and lower need in labor force which reduces the population retention capacity of the villages. Rábaköz can be characterized high, Hanság low or medium intensity of agricultural production. Forestry is not significant in the region the proportion of forests is just 9,5%.

Micro-region of Pásztó is mostly covered by forests with higher ratio of arable land in the hilly landscape of the South. On the hillsides of favorable conditions after wine production was abandoned there is flourishing fruit production. Pásztó micro-region has 32% forest cover.

Considering agricultural production two characteristic regions can be distinguished in Gönc micro-region. The ratio of arable land is high in Hernád valley, meanwhile in Zemplén Mountains the forests are dominant. The Southern villages of the micro-region belong to the Tokaj Wine Region Historic Cultural Landscape, UNESCO World Heritage Site which still hold the traditions of worldwide famous wine production. In the vicinity of Gönc fruit production is significant (apricot Pálinka). Forestry is an important economic sector; the average proportion of forests is higher than 40%. Naturally there are great differences in the region, in the valley there are settlements with 4-4% and in the mountains some settlements have more than 80% forest cover.

Tourism and recreation

Tourism infrastructure is underdeveloped in Csorna, recreational activities, with a few exceptions, are low in the region. The National Park Fertő-Hanság offers a great potential but mostly the strictly protected areas of the National Park (Lake Barbacs) belong to the micro-region which are not open to the public. Mostly the centre, study trails and the programs organized by the National Park are located around Lake Fertő with the exception of a few attraction (Study trail Hany Istók, Esterházy Madárvárta). Just in case of two settlements can we see considerable guest turnover (Csorna 1502, Farád 2226 guest nights spent in commercial accommodations in any other settlements none at all). Looking at the data reflecting tourism potential micro-region of Csorna has the lowest values with 3 807 total number of guests on the commercial accommodations and just 58 commercial accommodations (Hungarian Statistical Office, 2014).

The highest values describing tourism can be found in region of Gönc with 14 860 total number of guests on the commercial accommodations and 851 commercial accommodations, although the recreational opportunities are extremely uneven in the micro-region. A few settlements do not have at all any tourism potential, meanwhile Telkibánya, Regéc (castle) are of national significance. Telkibánya has the highest values in guest number at commercial accommodations (8387). The number of overnight stays per 1000 inhabitants is just slightly lower than the national average (2421). Significant tourism types are: nature and rural tourism.

Micro-region of Pásztó represents medium values among the study areas considering tourism potential with 4 787 total number of guests on the commercial accommodations and 308 commercial accommodations. In Pásztó the open-air bath and the hiking trails are used mostly by locals and visitors from the neighboring villages in spite of the fact that the location between Mátra and Cserhát mountains offers great potential. The pilgrim route to the holy well of Mátraverebély-szentkút crosses the region. The nearby Old Village of Hollókő, World Heritage Site can be reached through Cserhát Greenway from the region. The Palóc cultural trail and Nature Park Cserhát have more potential. In spite of the existing potential the number of overnight stays per 1000 inhabitants (212) is just one tenth of the national average (Hungarian Statistical Office, 2014). Apart from Szirák (3270 number of guests) just a few settlements have any commercial accommodations.

Accessibility

Major transportation corridors (M85, M86) cross micro-region of Csorna. Settlements along these corridors have great public transport accessibility, unfortunately the peripheral villages especially in Southern Rábaköz have really unfavorable accessibility. We can see similar dichotomy in micro-region of Gönc. The Southern and Western settlements have proper availability. In Zemplén Mountains the transportation infrastructure is underdeveloped, there are several dead end villages. Pásztó is located 80 km from Budapest, but there are no direct public connection to the capitol, the villages have even worse availability.

Economic value

According to Figure 6 micro-region of Csorna has the highest income values (927 376 Ft) among the study regions, the average per capita domestic income is 30% higher than the amount of Gönc micro-region. If we look behind the average values in all regions large differences

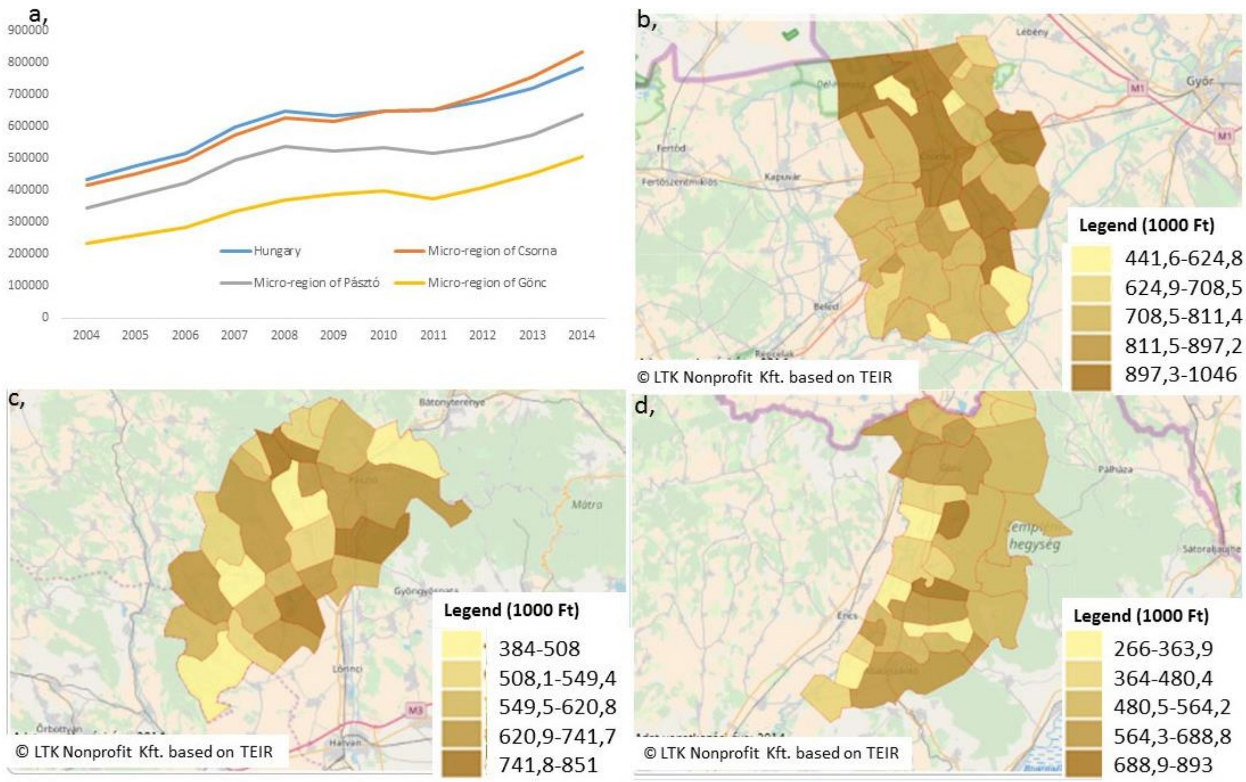

Fig. 6 Net domestic income per inhabitant (Ft) a, Comparison between national average and the study areas; b, Micro-region of Csorna; c, Micro-region of Pásztó; d, Micro-region of Gönc 2015; Source: www.teir.hu

can be found, especially in micro-region of Csorna the Northern-Sothern division is remarkable. Pásztó is situated east from the developed Budapest agglomeration and North to the development line Budapest-Miskolc. The average per capita domestic income is in micro-region of Pásztó 761 639 Ft. Gönc micro-region is one of the least developed areas of the country in 2012 the unemployment rate is 21,8 % (national average 9%), total income per capita 480 502 Ft (national average 810 000 Ft).

Comparing the studied regions (Fig. 7) different levels of landscape functions can be seen. Csorna is the most developed from economic point of view but here the lowest levels of landscape aesthetic, habitat values can be found. Of course generalization hides the territorial differences: the most problematic is the Southern part of Rábaköz due to the intensive agriculture where it is crucial to develop the ecologic network by enhancing multifunctionality of agricultural production. The natural, cultural values are stable base for tourism and recreational development in Gönc and Pásztó micro-regions. From tourism attractiveness Gönc has to be highlighted, where just the high differences in the level of tourism infrastructure hinders the effectiveness and profitability of tourism.

Landscape functions in rural development strategies

The most important goal in rural regions according to the New Hungary Rural Development Programme (2014) are "enhancement of the population retention capacity… and improvement of the income generation capabilities". The Programme highlights the need for maintaining proper level of ecosystem services. The Strategy states that the main functions of rural development policy are:

1. Preservation and sustainable use of landscape, natural assets and resources, maintenance of ecosystem services.
2. Processing and provisioning healthy and safe food.
3. Enhancing economic development and quality of life and strengthening local communities in rural areas.

The New Hungary Rural Development Programme mentions the term of ecosystems or ecosystem services 16 times. The strategy even highlights the importance of landscape management. Regarding the local strategies the Rural Development Programme of Rábaköz Leader Group which holds together the majority of settlements of micro-region Csorna formulates general framework of goals containing tourism development, enhancement of agricultural competitiveness. The strategy is not based on complex landscape assessment, the analysis focused on economic and social factors and description of the state of the environment (waste, sewage water, noise, water quality), in spite of the fact that the local stakeholders consider the most important potential of the region the tourism development based on natural values of Hanság and thermal water. In case of the wider environment, the landscape is not considered the wish of a few villages to become rural tourism or eco-tourism destinations remains just a wish. Diversification and enhancement of the ecologic value of the landscape require wide range of development projects, land use changes. However, the local strategy sets wide range of objectives even protection of natural values but unfortunately the focus is on business development, and the measures were reduced even further, containing only the support of organization of exhibitions, events (Rábaköz Rural Development Association, Local Development Strategy 2014-2020) (Table 1).

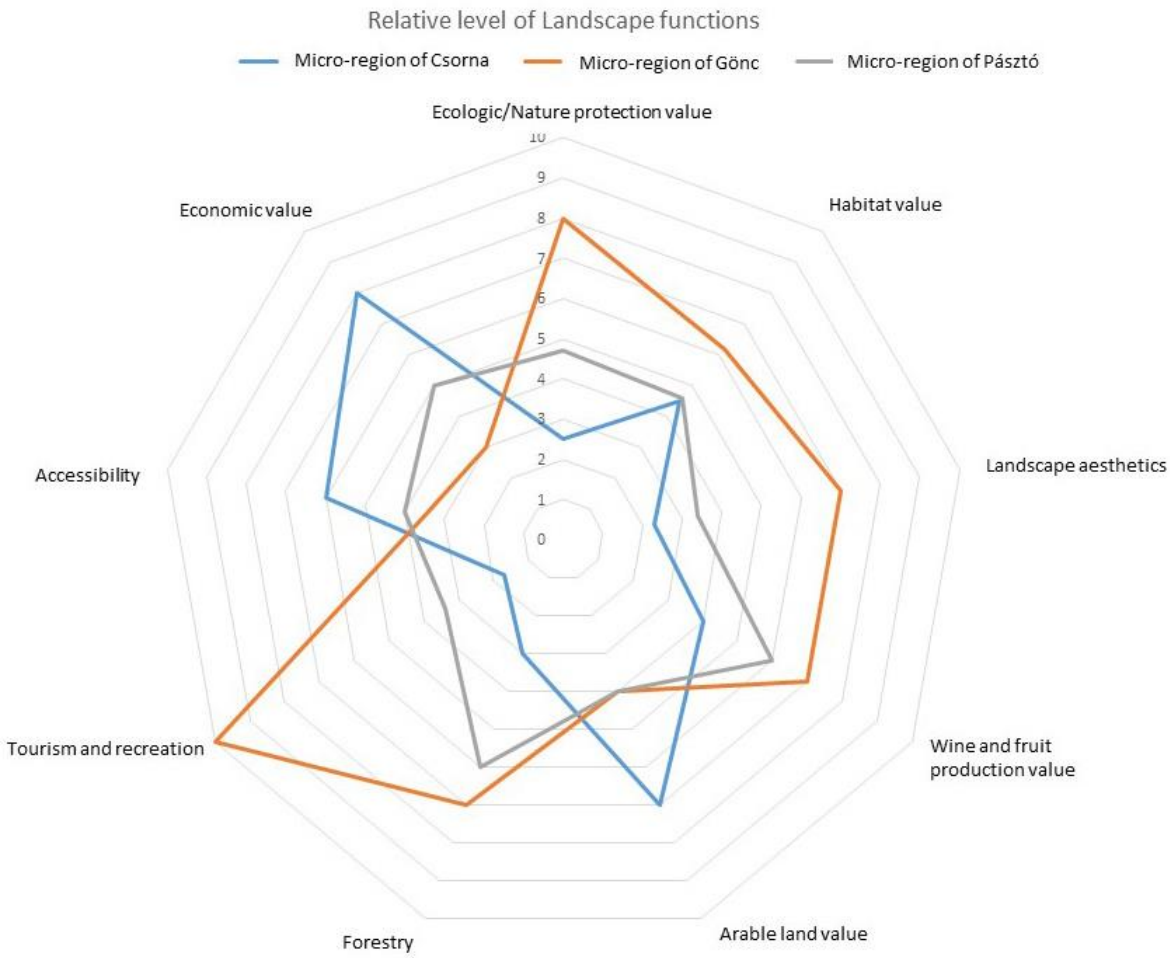

Fig. 7 General comparison of the level of landscape functions in the study areas

The Local Development Strategy adopted by Cserhátalja Rural Development Association (micro-region Pásztó) (HFS, 2016) sets wide range of objectives related to business development, small scale industrial development, tourism services, organization of events, strengthening local communities, preparatory documentation, safety investments, equal opportunities, low-waste issues, use of green energy (Cserhátalja Rural Development Association, Local Development Strategy 2014-2020) (Table 1).

The Local Development Strategy of Abaúj Leader Group (micro-region Gönc) among the general objectives as enhancement of economic development, quality of life, regional marketing, strengthening local communities, and education highlights the importance of tourism development, landscape management and diversification of agricultural production. The strategy highlights the importance of forestry and tourism potential of Zemplén Mountains, and lists the natural and cultural values (Abaúj Local Development Strategy, 2013). The analysis is focusing on potential and less on weaknesses. The concept is just mostly focusing on economic and demographic trends and agricultural production (Table 1).

The local development strategies do not focus on the real local resources, territorial differences nor potentials evolving from natural, cultural resources or local constrains. The only exception is tourism development where we can sometimes see the holistic spatial approach which intends to develop the region as a whole highlighting the development of the missing parts of the network and fosters local projects connecting tourism attractions, of course just in case there will be any initiatives.

In rural development it is extremely important to harmonize the ecologic, social and economic aspects/needs of different land use forms evolving from the landscape conditions. This means diversity, which is manifested in the proper level of varied landscape functions, considering the rural economy providing diverse and wide range of economic activities (Filepné et al., 2014; Valánszki and Filepné, 2015). Economic diversity offers favorable conditions for the local population as well. This needs rural development policy responding the spatial development trends and differences following the landscape conditions stressing and using synergies and regional or systematic initiatives in spite of isolated projects.

The disharmony of landscape functions weakens the population retention capacity of rural regions (Filepné and Valánszki, 2015). Because of the extreme complexity of land use systems, the effective and long lasting changes can be realized only based on processes initiated and elaborated by varied stakeholders including all sectors of rural economy. The proposed land use changes have multiple economic, social conditions but their complex realization is needed for the improvement of the population retention capacity. Unfortunately, in the present legal environment just isolated rural development projects can utilize and improve in complexity the local resources when just devoted local actors are capable to mobilize local engagement. While the rural strategies cannot reach the roots of local conflicts by deep landscape analysis the strategies will fail.

Table 1 General overview of the significance of landscape values in rural development strategies (Cserhátalja Local Development Strategy 2014-2020, Abaúj Local Development Strategy, 2013, Rábaköz Local Development Strategy 2014-2020);

XXX – The main priorities of the development concept are related to the function; XX – The development concept stresses the enhancement or development of the mentioned function; X - The landscape function is not stressed or neutral in the concept

Landscape function	Micro-region Csorna	Micro-region Gönc	Micro-region Pásztó
Nature protection value	X	XXX	XX
Habitat value	X	XXX	X
Landscape aesthetics	XX	X	XX
Wine and fruit production	XX	XXX	X
Arable potential	X	X	X
Forestry	X	X	X
Tourism and recreation	XX	XXX	XXX
Accessibility	X	XX	X
Economic value	XX	XX	XX

CONCLUSIONS

Economic, social and environmental factors need to be considered in order to develop rural areas in a sustainable way. Rural development strategies shall base on detailed landscape analysis assessing the landscape functions of the region. Just based on grounded assessment will be possible to elaborate effective rural development strategies which respond the needs of the landscape, and local communities. Exploring of the shortages of landscape functions in three study regions the rural development strategies were analyzed. Our general conclusion is that the strategies lack detailed and complex landscape analysis exploring the limits and potentials. The strategies supported activities mostly related to marketing, business development, and tourism services. Because of the financial shortages the range of supported activities were reduced recently which reduces the possibility of large scale complex programmes and gives way to small isolated developments.

Acknowledgements

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ASSESSMENT OF POSSIBLE UNCERTAINTIES ARISING DURING THE HYDROMORPHOLOGICAL MONITORING OF A SAND-BEDDED LARGE RIVER

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Abstract

The riverbed morphology of sand-bedded rivers is dynamically changing as a consequence of quasi continuous bedload transport. In the meantime, the dimension, size and dynamics of developing bedforms is highly depending on the regime of the river and sediment availability, both affected by natural and anthropogenic factors. Consequently, the assessment of morphological changes as well as the monitoring of riverbed balance is challenging in such a variable environment. In relation with a general research on the longer term sediment regime of River Maros, a fairly large alluvial river in the Carpathian Basin, the primary aim of the present investigation was to assess uncertainties related to morphological monitoring, i.e. testing the reproducibility of hydromorphological surveys and digital elevation model generation by performing repeated measurements among low water conditions on selected representative sites. Surveys were conducted with the combination of an ADCP sonar, GPS and total station. The most appropriate way of digital elevation modelling (DEM) was tested and 30-point Kriging was identified to be optimal for comparative analysis. Based on the results, several uncertainties may affect the reproducibility of measurements and the volumetric deviation of DEM pairs generated. The mean horizontal difference of survey tracks was 3-4 m in case of each site, however this could not explain all the DEM deviation. Significant riverbed change between measurements could also be excluded as the main factor. Finally, it was found that results might be affected greatly by systematic errors arising during motor boat ADCP measurements. Nevertheless, the observed, normalised and aggregated DEM uncertainty (600-360 m^3/rkm) is significantly lower than the changes experienced between surveys with a month or longer time lag. Consequently, the developed measurement strategy is adequate to monitor long term morphological and sediment balance change on sand bedded large river.

Keywords: hydromorphological surveying, digital elevation modelling, uncertainty, reproducibility

INTRODUCTION

Fluvial systems are characterised by a continuous change determined by various direct and indirect controlling variables, affected by natural and anthropogenic processes. One of the key driver of fluvial dynamics is sediment regime, affected by river flow regime, geological background and sediment availability. Consequent quality and quantity of sediment will also have a major effect on river morphology and bedform characteristics (Schumm, 2005). Therefore, if these are surveyed and assessed valuable information can be gathered in turn on the status of the investigated fluvial system (Sipos et al., 2012). The surveying and monitoring of the riverbed nevertheless can be highly challenging, since there is a limitation in space and time due to the rapidly changing environment, and in the meantime the execution of the measurements can also have difficulties (Sipos, 2006; Sipos et al., 2012).

A straightforward way of investigating morphological change is to perform consecutive bathymetric measurements on longer sections of a river (Laczay, 1968, Kiss et al., 2008). Hydromorphological measurements aim to reveal and monitor the development and changes of the river bed and they contribute to the analysis of the changes in morphology and dynamics. By generating digital elevation models (DEM) based on the measured datasets, volume differences can be determined in a certain time period, thus the bedload balance of the investigated river section can be assessed. Several devices can be applied for bathymetric measurements: wading rod, sonar, ADCP (Acoustic Doppler Current Profiler), total station, RTK GPS (Real Time Kinematic GPS), photogrammetric imaging, LIDAR (LIght Detection And Ranging; Defendi et al., 2010; Tiron et al., 2009; Gómez et al., 2010; Laczay 1968; Prónay and Törös, 2001).

Using the measured depth and height data obtained by the different equipments, digital elevation model of the study area can be set up, which serves as a basis for further assessments (Kertész, 1991; Jordán, 2007). However, its accuracy highly depends on the errors arising during surveying.

Geodetic and therefore bathymetric measurements can be affected by: random, systematic and gross errors which can occur even simultaneously (Detrekői, 1991, Wise 2000). Random errors are scattered around the true value, and the average of an infinite number of observations results the true value itself, therefore by increasing the number of measurements this type of error can be reduced. A systematic error distorts all measurements in one direction and by increasing the number of measurements the estimation of the true value will not be improved. A gross error significantly exceeds measurement accuracy, determined by random and systematic errors, it does not occur on a regular basis, and it can be filtered by increasing measurement number (Sárközi, 1991; Taylor, 1999). Consequently, during a riverbed survey it is of key importance to identify systematic and gross errors and to foster the reduction of random error by gathering and averaging more data. It is also worth to have control measurements during surveying, which can be used to estimate uncertainty and reproducibility of the assessments.

The main aim of the present investigation was to assess the overall uncertainty related to hydromorphological monitoring on a sand bedded large river. Secondarily, an attempt was made to determine the type and significance of errors that may affect the deviations experienced during instantly repeated surveys on the selected sites. Consequently, it was possible to decide whether the errors related to the measurement allow the comparison of surveys performed to track longer term changes in morphology.

STUDY AREA

River Maros is the largest tributary of River Tisza having a length of 760 km; the investigated study sites are located along its 175 km long lowland section (Fig. 1). The discharge of the river fluctuates considerably: during low water periods it is approximately 20-30 m^3/s at the Makó gauge station, while at floods 1600 m^3/s discharge can also occur (Sipos and Kiss, 2003). The slope is relatively high in case of the whole lowland section and decreases from 40 cm/km (Lipova) to 10 cm/km (Deszk) (Fig. 1). Mean flow velocity is 0.5-1.0 m/s. The river transports a significant amount of bedload, having an annual value of 28 000 t at Deszk (Bogárdi, 1971). The bedload of the alluvial Maros is composed mainly of coarse and medium grainsize sand and a subordinate amount of gravel (Csoma, 1975). The river has also a significant amount of suspended sediment, which can reach 8.3 million t/year (Bogárdi, 1971).

River regulation in the 19-20th centuries greatly affected the river and flood control works caused significant changes (Kiss and Blanka, 2006): the length of the lowland section decreased from 260 km to 175 km (Urdea et al., 2012), furthermore river slope and stream power of the regulated river, transporting huge amount of sediments, increased. Sections with bank protection (e.g. downstream from Lipova and near Makó) slightly changed, more dynamic responses could be observed on sections without additional interventions. The investigated lowland section is characterised as a transition between a braided and a meandering channel pattern. The channel is mostly shallow, and in some places intensive bank and island formation can be observed (Sipos, 2004).

Nowadays the most important human activity on the investigated section is gravel and sand quarrying from the riverbed. The mining activity has been continuous since the 1970s; however, from the 2000s it became even more intensive above Arad (Urdea et al., 2012).

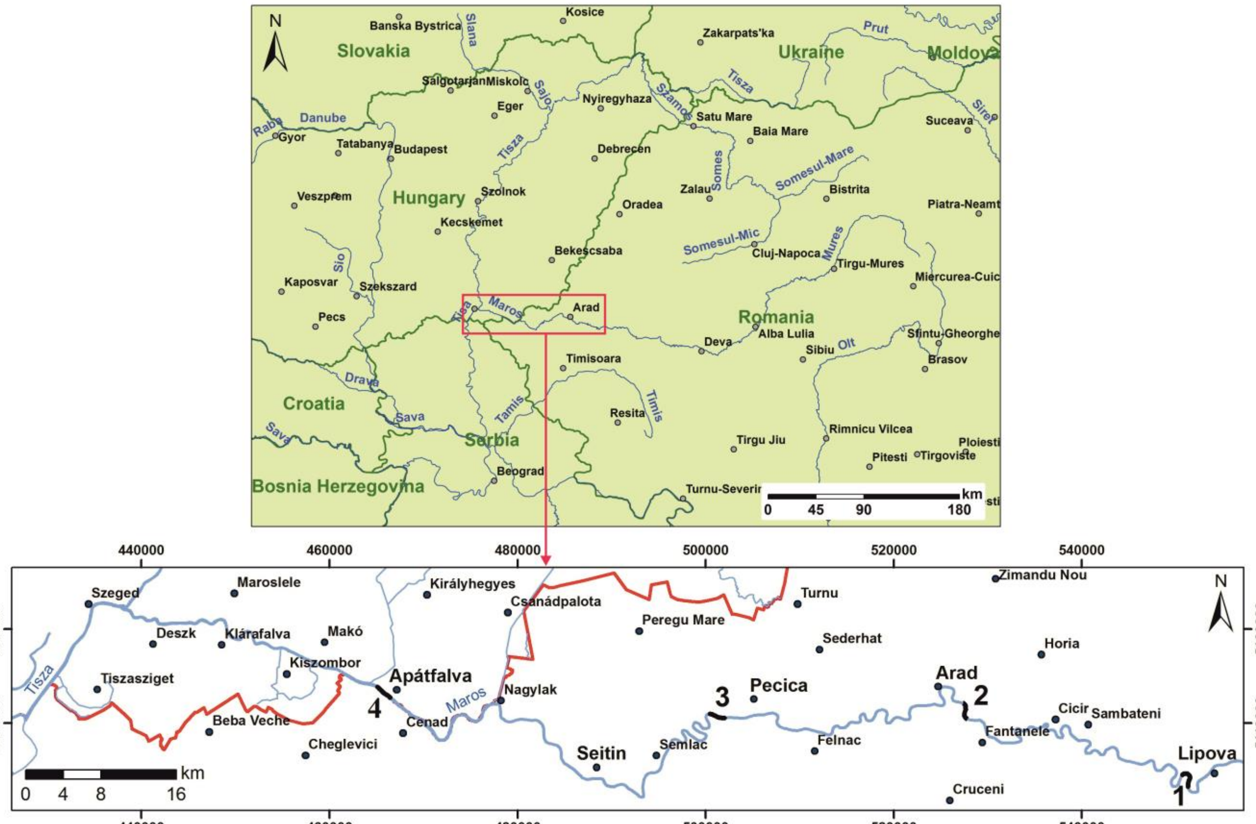

Fig. 1 Location of the study sites

In this study 4 sites were analysed, representing sections with different sediment dynamics as a consequence of in channel quarrying, mostly apparent on the Sambateni-Cicir section of the river (Fig. 1). The first site at Lipova is located in a meander upstream of the major sand exploitation on the river. The river bottom is composed of sandy-gravelly sediments. The second site at Arad is directly downstream of the excavations. The bed of the river here is highly paved by gravels, sand is carried away in the lack of sediment supply as a consequence of in channel mining. The other two sites at Pecica and Apátfalva are characterised by coarse and medium sand bedload and dynamic channel processes manifested in the formation of various bar forms and fluvial islands.

The length of the investigated sites was between 250 and 500 m. Their morphology is similar in the sense that each includes a riffle section and an adjacent pool section. The riffles in each case are a complex of bars and/or islands. The measurements in this study were performed mainly on the riffle sections.

METHODS

Repeated channel surveying was performed at low-water at each of the 4 sites to estimate the overall uncertainty of measurements. At low water conditions bars were exposed at each site, thus subsurface bathymetric and above surface geodetic measurements were applied together with the exception of the Lipova site. The comparability of the surveys can be difficult due to the inaccuracy of cross-section tracking, the differences in data density and the differences in elevation modelling. The temporal difference between the start of the two consecutive surveys was approximately one hour to minimize river bed changes originating from bedload transport. Cross-sections were allocated to represent variable morphology within a site and to include both underwater and exposed surfaces if possible. The distance between two cross-sections did not exceed the half of river width. The tracking of cross-sections was carried out with Trimble Juno navigational GPS with a spatial accuracy of 2-5 m.

For surveying underwater sections a light weight motor boat equipped with a Rio Grande ADCP was used. Depth data was recorded at 1.5m in average at the given speed of the boat. To each depth data measured by the ADCP, surface coordinates were provided using a Topcon RTK GPS. This device has high horizontal and vertical measuring accuracy.

For surveying the exposed parts of the channel a SokkiaSet 650rx total station and a Topcon RTK GPS were applied. The total station was used where the accuracy of the RTK GPS was low, e.g. near the river bank under the trees.

At the Apátfalva site 10 cross-sections and 5 longitudinal sections, while in case of the other areas 5 cross-sections and 5 longitudinal sections were measured repeatedly (Fig. 2). During the remeasurement new GPS base station was set up and a new base point was assigned to simulate the difference between consecutive surveys and to include the systematic error related to base correction.

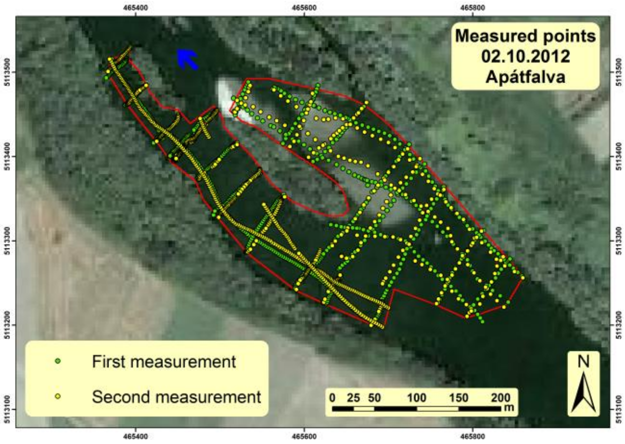

Fig. 2 Datapoints of the first and the repeated survey at the Apátfalva site

After arranging the raw datasets from the different devices in one spatial data infrastructure, digital elevation models (DEM) were set up for all areas and surveys under similar conditions to assess the differences. In case of all study sites and both surveys the same reference level was used to determine the volume deviation of DEMs. Models were generated using linear Kriging with varying the number of sampling points used for interpolation. In case of the Apátfalva site a TIN model was also generated. For making comparisons riverbed elevation maps and volumetric maps with and without distortion correction were generated. Sediment volumes were calculated based on the resulted digital elevation models using reference levels determined in our previous studies for the first and the second survey too (Sipos et al., 2012; Právetz and Sipos, 2014).

Beside volume differences the horizontal discrepancy of repeated measurement tracks was also assessed. For the determination of spatial deviation in a given section a polygon was created using the data points of the two measurements, and polygon area was divided by the length of the section resulting a value representing mean horizontal difference. The mean tracking uncertainty for a site was calculated by averaging cross-sectional results.

RESULTS AND DISCUSSION

Assessment of DEM deviations

The DEMs generated by TIN and Kriging at the Apátfalva site are presented in Figure 3. Concerning the general morphological setup and main forms the two models yielded very similar results. If temporal differences are considered the main deviation between the first and second survey appeared on the lower section of the study area: a side bar along the left bank and a smaller depression at the right bank almost disappeared on the second elevation model (Fig. 3). Both forms were related to areas where data density was limited, therefore interpolation difference could be more significant. Noteworthy deviations could be observed concerning the slip face of the main bar form on the upper half of the study area (Fig. 3).

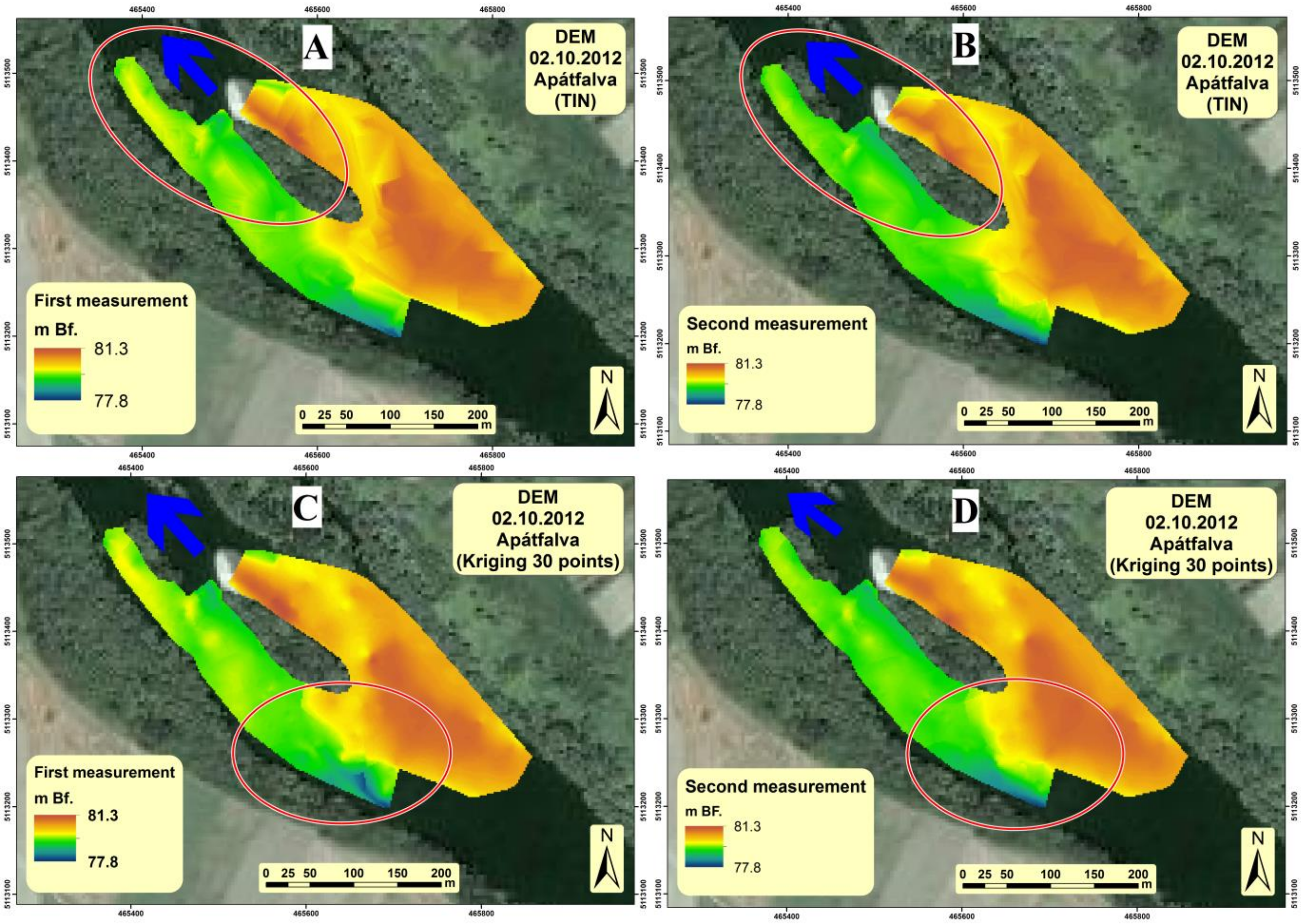

Fig. 3 Resulted DEMs using TIN (A, B) and Kriging (C, D) at the Apátfalva site

Although in general TIN and Kriging yielded similar results, a significant difference was identified between volumetric deviations. Concerning the TIN models the difference between the two consecutive models was 1400 m^3, three times higher compared to the volumetric deviation in case of Kriging. When the number of neighbouring sampling points used for the interpolation is varied it is obvious that 5-15 points resulted a much higher (500-700 m^3) volumetric difference than 25-35 points (300 m^3), and that by extending further the number of sampling points deviation started to increase again (400-500 m^3) (Fig. 4). This pattern can be linked to the spatial organisation of data points, namely that there was a 1-2 m spacing between points along a section and that the distance between cross-sections was 40m in average. Consequently, if 25-35 points are included then the interpolation accounts for two neighbouring cross-sections and also samples the longitudinal sections. If less points are considered it can happen to areas located close to a section that samples are only taken from that section, as the others get out of the reach of the interpolation. This can be especially problematic in case of cross-sections, since the direction of bedforms has a significant longitudinal component, thus the interpolation can have a higher error. On the other hand, if the number of sampling points is too high, not only the neighbouring cross-sections but farther sections can also affect the interpolation, thus deviations between the two models can accumulate. Based on the results above, for further comparisons a 30-point Kriging was applied for DEM generation. Consequently, in case of the Apátfalva site the value of aggregated DEM uncertainty was 300 m^3. In other words, if a deviation higher than this is experienced between two surveys, it can truly be assigned for morphological changes and the rearrangement of the riverbed.

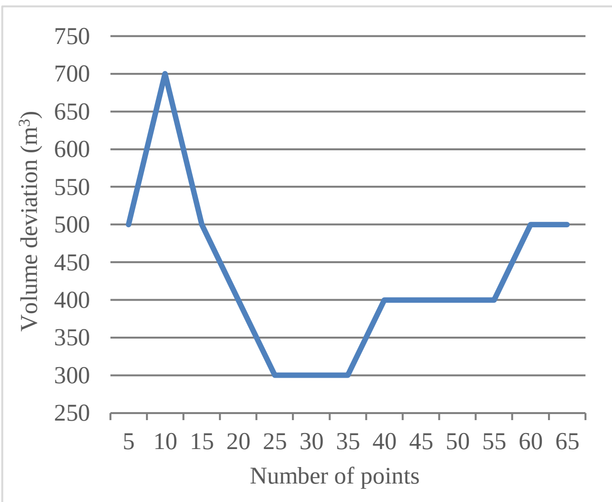

Fig. 4 Sediment volume deviations based on the number of points taken into consideration during Kriging

Comparison of site specific DEM deviations

For the remaining three sites the interpolation method described above was applied for the comparison of consecutive surveys and to determine the aggregate uncertainty of hydromorphological measurements at a given site. In case of the Pecica site the DEM pair showed the most significant deviation at the left flank of the main side bar. During the first measurement a pronounced protrusion can be observed here (Fig. 5 A, B). The deviation is accounted for the difference in the track of longitudinal sections passing the bar form (Fig. 6). Concerning the Arad site volumetric deviation can mostly be related to a depression at the right bank, anyway the DEM pair show little difference (Fig. 5 C, D). No major difference in DEMs was observed in case of the Lipova site, which is partly due to the relatively simple morphology of this section (Fig. 5 E, F).

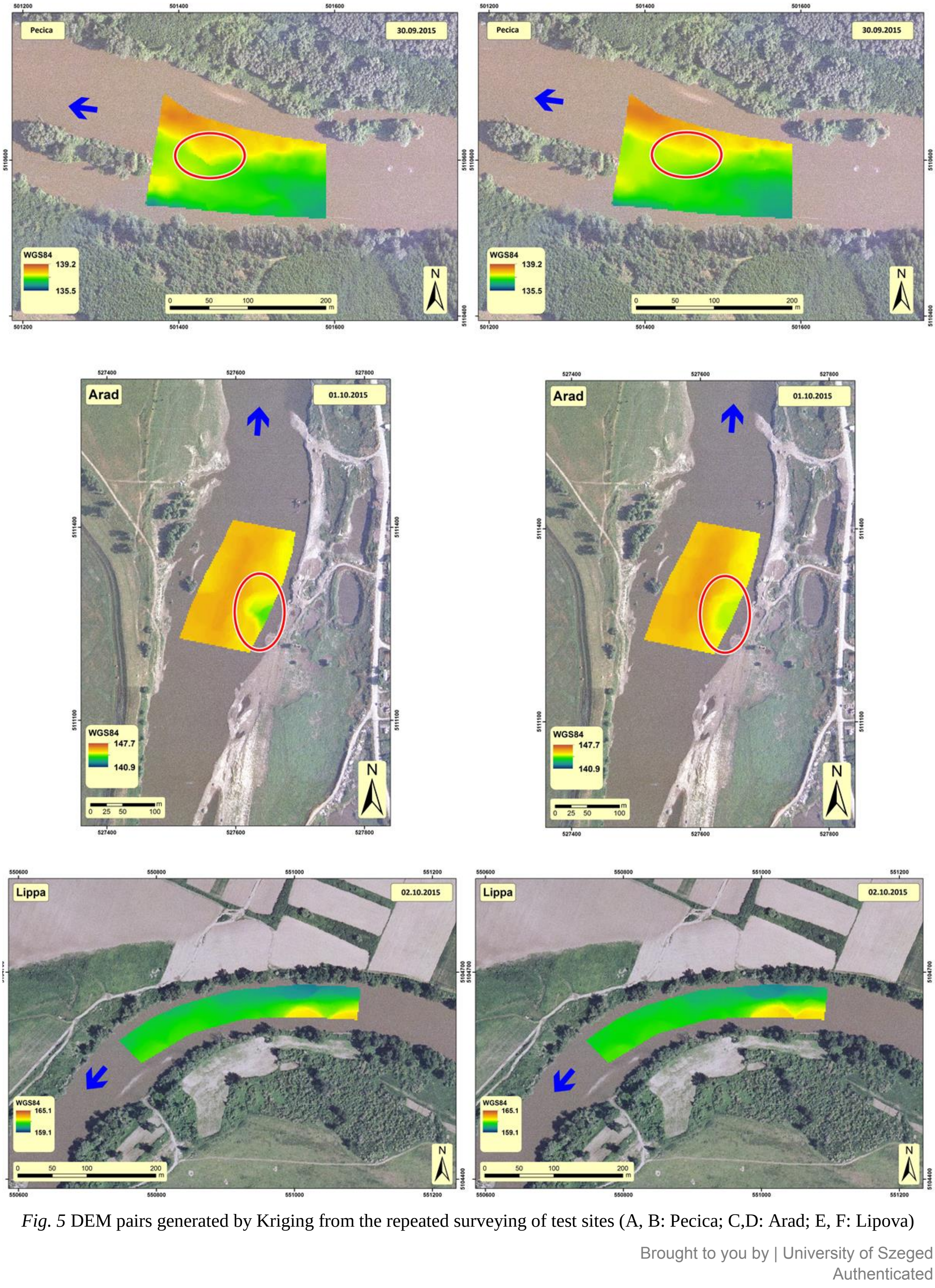

Fig. 5 DEM pairs generated by Kriging from the repeated surveying of test sites (A, B: Pecica; C,D: Arad; E, F: Lipova)

In order to make site specific DEM deviation values comparable, results were normalised to 1 river km (rkm) in case of each site (Table 1). The lowest normalised deviation can be observed at Apátfalva (600 m^3/rkm), while the highest at Pecica and Lipova (3600 m^3/rkm). Considering all of the studied sections mean volumetric deviation is 2300 m^3/rkm.

Possible sources of deviation

Deviations suggested to be derived either from improper tracking of the survey lines, changes of underwater bed forms, or the inaccuracy of the elevation data measured by the different devices. As the surveys were performed using different equipment, it is possible to compare the contribution of different techniques to the overall uncertainty.

At sites, where both underwater (ADCP) and exposed bar surface (GPS, total station) surveys were performed it was obvious that the tracking of survey paths was naturally less accurate if measurements were done from the motorboat (Fig. 6). This was especially a problem: 1) when crossing the thalweg, where flow velocity is the highest; 2) at near bar very shallow areas, where navigation is difficult; 3) and along longitudinal sections, where a little oversteering of the boat can lead to significant path leaving. In general, the mean horizontal difference between tracks was 3-4m (Table 1). The highest value was experienced at the Arad site, surveyed mostly from the boat and being morphologically complex (Table 1). The lowest value was received at Lipova, where exclusively a boat survey was made, but navigation was much easier as water depth was greater and morphology was less complex. Consequently, one would expect that the lowest track difference will result the lowest DEM deviation and the opposite if track difference is higher. This is not the case, however, because if mean horizontal track difference and volumetric deviation are plotted against each other no relationship can be observed (Fig. 7).

DEM deviations may also be explained by the assumption that river bottom morphology did change between the two measurements regardless of the short repetition time and low water (low energy) conditions. Nevertheless, this explanation is contradicted by the fact that the two downstream sites, with a highly mobile sandy bottom, did not show higher DEM deviation than those having a paved and more stable river bottom (Table 1).

Another issue is the accuracy of elevation measurements. The absolute precision of at-a-point sonar data (±10 cm) is naturally lower than RTK GPS or total station elevation data (± few cm). On the other hand, as during the repeated measurement the same devices were used at the same sections, the difference at the given high number of sampling points should not be affected by at-a-point precision.

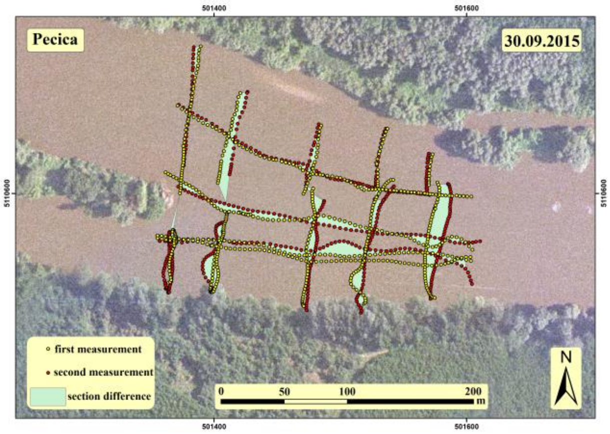

Fig. 6 Horizontal difference of survey tracks in case of the Pecica site

Consequently, as the highest DEM deviation is observed at the Lipova site, where the riverbed is less mobile, track difference was the lowest and only ADCP was used for surveying; it is suggested that a systematic error related to ADCP use can be the major source of overall uncertainty. Knowing volume difference and the area of the surveyed site it is possible to calculate the mean elevation difference between the DEM pairs (Table 1). Even the largest difference (8.1 cm), experienced in terms of the Lipova site is small enough to be easily achieved by a systematic difference in the submerging of the measurement device.

Finally the average elevation difference of consecutive ADCP sonar datapoints was also calculated (Table 1). If beside this the proportion of ADCP surveyed area is also considered, it is obvious that there can be a considerable systematic error, primarily related to ADCP measurements, affecting the DEM results (Table 1).

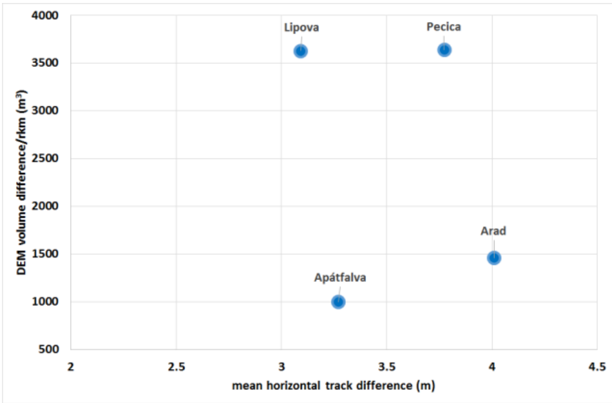

Fig. 7 DEM volume difference plotted against mean horizontal track difference

Table 1 Volume and cross-section deviations for uncertainty assessment

Site	DEM volumetric deviation (m^3)	Mean deviation of survey tracks (m)	Mean elevation diff. (cm)	Mean ADCP elevation diff. (cm)	Proportion of ADCP survey area (%)	Normalised volumetric deviation (m^3/rkm)
Apátfalva	300	3.3	0.4	5.0	37	600
Pecica	910	3.4	3.6	11.2	62	3640
Arad	307	4.0	1.3	2.9	72	1460
Lipova	1307	3.1	8.1	11.4	100	3630

CONCLUSION

In this paper measurement and evaluation uncertainty was assessed using repeated measurements on representative sections of River Maros. After generating DEMs with different interpolation methods and settings 30-point Kriging was considered to be optimal for further comparative analysis of consecutive surveys.

Several uncertainties were identified in relation with surveying, which may affect the reproducibility of measurements and the final difference in DEM pairs generated. After a detailed comparison of sites, the role of these could be qualitatively and quantitatively assessed. The mean horizontal difference of survey tracks, derived from RTK GPS measurements, was 3-4 m in case of each site, which is in correspondence to the accuracy of the navigational GPS (2-5m) used for tracking the previously appointed survey path, thus better values can hardly be expected. Tracking is highly affected by navigational problems in shallow water and at the thalweg. However, if the result of each site is considered this uncertainty will not explain all the deviations experienced in the DEM pairs, since the largest deviation was observed where tracking was the most accurate (Lipova site).

At a point difference in measurement precision and riverbed change were considered to be less significant in affecting the overall uncertainty experienced. Therefore, we suggest that systematic errors related to the use of ADCP can be the most significant source of error during consecutive surveys. A few cm difference in the submerging of the device under water can result the same order of magnitude deviation as experienced during the uncertainty assessment. Therefore, it is strongly advised that the ADCP or sonar has to be mounted identically during consecutive measurements, weight distribution in the boat has to be balanced, and surveying speed preferentially should also be of similar throughout the monitoring activity.

The calculated and normalised volumetric DEM deviation at the different sites ranged between 600 and 3600 m3/rkm, an average value of 2300 m3/rkm can be regarded as the overall uncertainty of surveys at the present environment and measurement setting. This is significantly lower than deviations experienced if measurements with a month or longer time lag are compared (Právetz and Sipos, 2014). As a result, the here applied survey strategy is adequate for monitoring longer term changes of the river bed of River Maros.

Acknowledgements

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ASSESSMENT OF ECOLOGICAL VALUES OF GREENING LANDSCAPE ELEMENTS IN THE GREAT HUNGARIAN PLAIN

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Abstract

The research examines the effects of agricultural subsidies on the landscape structure. According to the hypothesis, greening – which has been introduced as part of the European Union's Common Agriculture Policy (EU CAP) reform –, if it is properly controlled and applied, can be a suitable tool for habitat network development. Landscape elements eligible for greening can function as significant landscape structural elements, and can promote the achievement of goals e.g. in the preservation of biodiversity. As part of this research, field surveys were performed in 2016 and 2017 in the Great Hungarian Plain, where significant landscape elements were assessed and documented in the sample area. During the research, Shape Index and Fractal Dimension Index values for polygonal elements were calculated based on their current extensions in 2016 and in 2017. In line with my basic hypothesis, eligible landscape elements (such as hedgerows, stonewalls, shadoofs and infield trees) do not possess extraordinary ecological values, nor can their persistence be guaranteed solely with greening subsidies. Therefore, they may also not be able to fill their role in the protection of landscape structure and biodiversity in the long term.

Keywords: greening, landscape element, EFA, landscape structure, landscape indicator, Shape Index, Fractal Dimension Index

INTRODUCTION

According to the 2013 CAP reform, EU member states are obliged to use 30 percent of their agricultural subsidies for environmental goals, collectively called as greening. In the greening starting in Hungary in 2015, farmers have to fulfil criteria in three areas in order to receive subsidies: (1) maintaining permanent grasslands, (2) crop diversification and (3) designation of ecological focus areas (EFAs) (Greening regulation, 2015). Landscape planners could be especially involved in the designation of EFAs, as these can mostly be identical to landscape elements which are to be protected or have ecological values (Allen et al. 2012). The main goal of the new agricultural subsidies is the protection of water and soil quality, and the preservation of biodiversity and rural agrarian landscapes (EU regulations 1307/2013 (44)). A long-term goal is the adaptation and mitigation of climate change. The experiences of the first year are worrying in terms of whether opportunities in landscape development provided by these subsidies can be exploited, and whether the measures serve the protection of truly valuable conservation areas (Matthews, 2015; Máté, 2017). This study attempts to answer a question if among greening landscape elements, those elements are really subsidised which are justifiably more stable ecologically. Thus, it is examined whether the selection of eligible landscape elements is a result of consequent, professional decisions or they may have been selected without proper consideration, rather accidentally – which would constitute a long-term threat. The subsidies may have drawn the attention of not only the farmers but also landscape planners, ecologists, conservationist and other nature-related professionals, as they could effectively contribute to the improvement of landscape structure connectivity, to the increase of biotope network stability and even to halting the decrease of biodiversity (Máté and Kollányi, 2016).

The delivery of obligations and undertakings of Hungarian farmers is supported by the Hungarian Land Parcel Identification System (MePAR). MePAR is the exclusive, country-level system used in the subsidy processes (MePAR regulation, 2015). On the online interface, every farmer and interested parties can search for their own parcel, of which they can learn further information thanks to the rich GIS background database.

At the end of 2015, the database has been extended with greening landscape elements, thus farmers can see which of them are EFA eligible. According to the regulation, EFAs can be: fallow lands, terraces, landscape elements, buffer strips, eligible forest edges, agroforestry, short-rotation coppice, catch and cover crops, and nitrogen fixing crops (Kovács et al., 2015). Landscape elements can be the following habitats: field margins with trees, single trees, tree lines, tree and shrub groups, field margins, ponds, and ditches. The preservation of permanent grasslands and crop diversification are important for landscape structure mosaics. In addition, the conservation and creation of EFAs may bring significant changes in the ecological and biotope network.

The protection of the ecological networks is especially important as nowadays, fragmentation – the breakup of natural habitats – is one of the most significant threats to communities (Didham, 2010). The role of landscape ecology is examining correlations in patterns, i.e. landscape structure, and various ecological processes (Turner, 1989). Human activities have a large impact on patterns which also has an effect on biodiversity (Moser et al., 2002). During land use, natural mosaics and man-made patches form a fragmented landscape, where interconnection of natural habitats is not ensured in all cases (Turner et al., 2001). Bigger interconnected natural or semi-natural areas have become very rare by today. Fragmentation negatively affects the survival of communities and does not only result in a shrinking habitat, it can also have negative consequences regarding biodiversity and species distribution (Mairota et al., 2013). The widely known island biogeographical theory of MacArthur and Wilson (1967) can be applied with slight adjustments also to mainland habitat islands. According to the theory, larger islands have more species, and the larger the distances of the islands, the lower the number of species is. Wilson and Willis (1975) recognised that laws of island biogeography have important consequences for planning in protected areas. Thus, it is preferable that the protected area be in a single block; have a rounded shape, i.e. a low perimeter-area ratio; and – if fragmented – have its fragments close to each other and have corridors between them. It is important however to mention a debate in conservation biology still current today: the so-called SLOSS debate. It raises the question whether a fewer but larger, or more but smaller patches make the planning of protected areas more effective regarding biodiversity and connectivity.

Landscape indicators have proven to be very popular and efficient in the quantification of landscape patterns (Gustafson, 1998). Most landscape indicators are based on the perimeter-area ratio. One of the most basic patch-level indicator is the Perimeter-Area Ratio (PARA) itself. Most landscape ecology indicators examining patch shapes are based on this ratio. The most common criticism of the PARA indicator is that its value may change with the size of the patch. This error is fixed by the Shape Index (SHAPE) indicator which compares the shape of a patch with a square of the same size, and which is widely used in landscape ecology researches (Forman and Godron, 1986). Another patch-level index based on the perimeter-area ratio is the Fractal Dimension Index (FRAC). It is well known that the more compact shape a patch has, the more stable habitat it can provide for – as it is less affected by the so-called edge effect (Helzer and Jelinski, 1999). Shape Index has an interval of 1 to +∞, while Fractal Dimension Index has an interval of 1 to 2 (Szabó, 2009). Both indices indicate a regular patch shape with 1, and higher values mark a higher irregularity.

In this study, greening elements surveyed in a Hungarian sample area are examined using the demonstrated landscape indices, in order to have a clearer picture on what ecological values do those greening landscape elements have which are supposed to meet the goals of biodiversity protection and landscape structure.

STUDY AREA

The sample area is an about 120 km^2 large on the Dévaványa-Ecseg fluvial plains, in the operational area of Körös–Maros National Park, on the south-western edge of the former Great Sárrét region (Fig. 1). An important characteristic of the area are the mosaics of saline plain remnants in the vicinity of the settlements Ecsegfalva and Dévaványa. These saline plains had been formed by secondary salinisation following the regulation of river Tisza (from 1846). The floodplain grasslands, once rich in grass, had dried out, become salinated, and been placed under cultivation by local inhabitants (Sallai, 1999). However, even the ploughing of grasslands had not caused the complete extinction of native species, thus certain species of the former plain grasslands have been preserved in the secondary saline communities and weed communities with wild flowers peculiar to the Transtisza region (Dövényi, 2010). Some parts of the sample area are under various nature protections – there are local protected areas, highly protected areas, Natura 2000 and National Ecological Network core areas, buffer zones and corridors; also, the entire sample area is part of the “Dévaványa and surroundings high natural value area”.

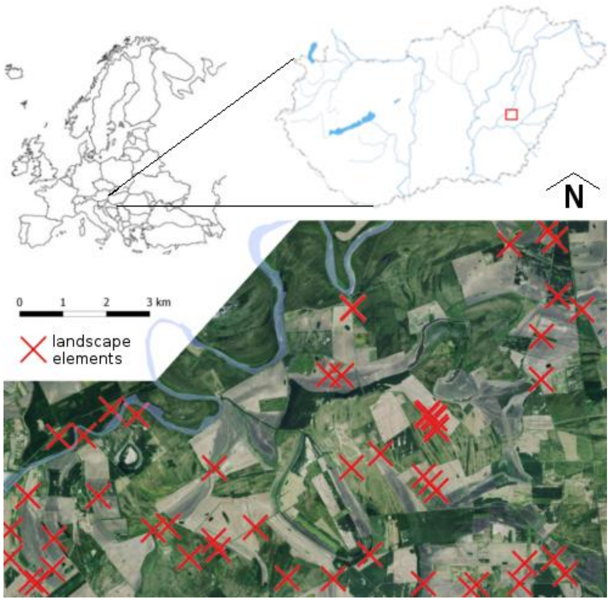

Fig. 1 Location of the sample area and assessed elements

The region belongs to the significant agricultural areas of Hungary. The islands of protected areas are surrounded by intensively cultivated arable lands. In the designation of the sample area, both natural and artificial landscape boundaries were taken into account. Thus, the sample area is bordered by the unregulated river bends of Hortobágy-Berettyó to the west, road 4205 connecting Ecsegfalva and Dévaványa to the north and to the east, and dirt roads with larger agricultural traffic to the south.

METHODS

Preparations for the field survey were made using QGIS 2.10.1 Pisa (QGIS, 2010). EFA eligible elements were displayed using MePAR symbols. The path of the field survey was planned in a way that it passes by all EFA elements in the sample area. The first field survey was performed between 12 July and 13 August 2016, and the second one between 8 and 10 September 2017. Both EFA elements and other non-EFA elements – in total, 48 point, linear and polygonal elements – were assessed. Among the data assessed on the spot were: EFA type verification, general ecological and condition attributes, species composition, GPS coordinates for later display on map, and photo documentation of all elements.

As part of processing the field work, a GIS database was built which contained all the assessed elements. The shapes of the assessed patches were drawn based on their shapes in MePAR in case of EFA landscape elements, and as a result of merging field survey data with cartographic post-production in case of non-EFA elements. The Shape Index and the Fractal Dimension Index of these shapes was then calculated in ArcGIS 10, using the V-LATE extension. In the GIS database, Shape Index and Fractal Dimension Index values and photo ID numbers were registered, along with year, the fact of EFA eligibility, ecological condition and species composition, and in some cases an additional note (e.g. terminated EFA eligibility or disappeared element) (Table 1). The structure of the database allows for incorporating results of studies in the following years as well, and for comparison of the results.

In this study, only the Shape Index (SHAPE) and Fractal Dimension Index (FRAC) of patch-like EFA and non-EFA landscape elements were examined, as their values can be calculated only for this type of elements. 22 landscape elements were examined, which can be divided into two categories: tree and shrub groups, and ponds. First eligible and non-eligible elements were examined using Student’s t-test, but as the conditions of normality and homogeneity of variance were not fully met, a simpler yet more reliable analysis was needed. After individually calculating both indices of each 22 patch-like elements, the averages of the values were calculated in each group for each year, differentiating EFA and non-EFA elements. For a preliminary overview, understanding and sanitisation of data, they have been displayed as bar graphs in Microsoft Excel software.

During the field surveys, pictures were taken of every element, which can be used not only for documenting year-to-year changes but also for visually comparing “protected” and “not protected” landscape elements. The collation of the photo documentation was an especially important step of the annual field survey, as it could also be regarded as an annual monitoring of landscape elements in the sample area. The photo documentation was performed for all surveyed elements both in 2016 and 2017. As for linear landscape elements, there was no basis for comparison, as tree lines defined in the greening starting in 2015 were still not visible in MePAR in summer 2016. It should also be noted that the EFA designation of tree lines are professionally objectionable. As

Table 1 Surveyed polygonal elements and their attributes

Nr	Landscape element type	Dominant species	EOV coordinates of centroids		2016			2017		
			X	Y	EFA	SHAPE	FRAC	EFA	SHAPE	FRAC
001	tree and shrub group	*Robinia sp.*	193585.88	780233.37		1.24	1.37		1.24	1.37
002	tree and shrub group	*Robinia sp.*	192963.25	780231.38	x	1.39	1.44	x	1.20	1.43
003	tree and shrub group	*Robinia sp.*	192453.76	780685.41	x	2.09	1.53	x	2.09	1.53
004	tree and shrub group	*Robinia sp., Fraxinus sp.*	192368.25	780867.80	x	1.68	1.47	x	1.37	1.43
006	tree and shrub group	*Robinia sp.*	193359.50	781262.40		5.61	1.64		5.61	1.64
014	tree and shrub group	*Robinia sp.*	197110.67	787860.39		1.12	1.30		1.12	1.30
016	tree and shrub group	*Robinia sp., Populus sp.*	196268.89	789875.49		1.15	1.50		1.15	1.50
019	pond	*Phragmites sp.*	196140.55	790019.94		1.35	1.38		1.35	1.38
020	tree and shrub group	*Populus sp.*	195972.77	790024.31		2.39	1.59		2.39	1.59
021	tree and shrub group	*Populus sp.*	195884.43	790061.47		1.20	1.49		1.20	1.49
024	tree and shrub group	*Robinia sp., Salix sp.*	194492.93	790048.27	x	1.25	1.50	x	1.25	1.50
025	tree and shrub group	*Robinia sp.*	195334.15	788756.92		1.25	1.36		1.25	1.36
031	tree and shrub group	*Robinia sp., Salix sp.*	198939.82	792832.33	x	1.58	1.42		1.58	1.42
033	tree and shrub group	*Robinia sp., Salix sp., Quercus sp., Fraxinus sp.*	197989.55	792549.66		2.25	1.42		2.25	1.42
034	tree and shrub group	*Fraxinus sp.*	197051.64	792482.59	x	1.81	1.48	x	1.79	1.48
035	tree and shrub group	*Robinia sp.*	192918.89	792775.08	x	1.41	1.38		1.41	1.38
036	tree and shrub group	*Robinia sp., Salix sp.*	192588.15	793034.73	x	1.27	1.37	x	1.27	1.37
038	tree and shrub group	*Salix sp., Robinia sp.*	192368.43	791992.98		3.60	1.67		3.60	1.67
039	tree and shrub group	*Robinia sp.*	192342.62	790979.08		1.42	1.53		1.42	1.53
040	pond	*Carex sp.*	192213.82	790846.07	x	1.19	1.35	x	1.19	1.35
044	tree and shrub group	*Robinia sp.*	193130.75	785019.50		3.10	1.58		3.10	1.58
047	pond	*Salix sp., Phragmites sp.*	193684.56	783867.91		1.16	1.37		1.16	1.37

of 2017, the MePAR layer for tree lines is available. Unfortunately however, on the 120 km^2 sample area there is not a single official EFA tree line.

RESULTS

Shape Index and Fractal Dimension Index values of the assessed elements

The averages of SHAPE values for each eligible and non-eligible EFA types in 2016 and 2017 can be seen on Figure 2. It can be stated that in general, EFA-eligible patch-like landscape elements have lower SHAPE values in the sample area in both years, thus they can be regarded as ecologically somewhat more stable than non-eligible elements. The figure shows that eligible landscape elements in 2016 have a higher SHAPE (1.52) value, thus are ecologically somewhat less stable than eligible elements assessed in 2017 (1.45).

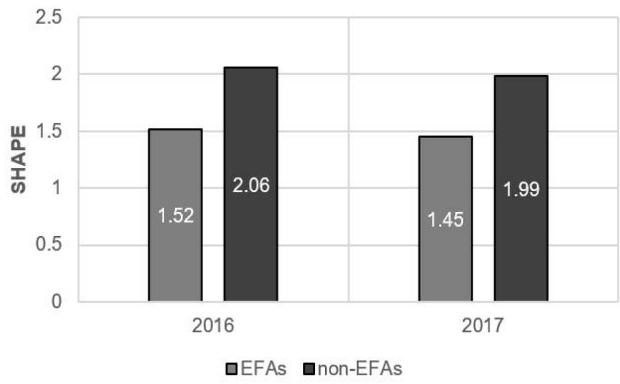

Fig. 2 Average SHAPE values of the assessed elements in 2016 and in 2017

No significant change can be demonstrated in FRAC values in the assessed EFA landscape elements from 2016 to 2017 (Fig. 3), and the change in FRAC values of non-EFA elements is also negligible from 2016 to 2017 (0.01).

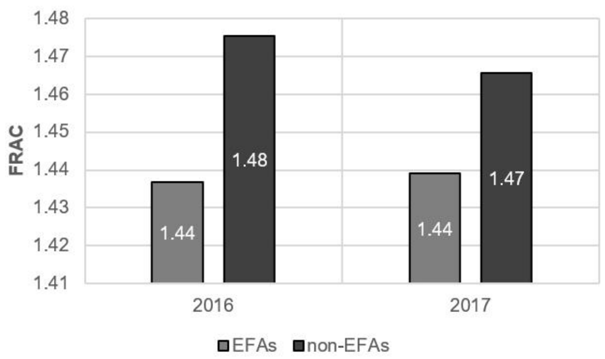

Fig. 3 Average FRAC values of the assessed elements in 2016 and in 2017

There is a similar tendency in the 2016 and 2017 SHAPE values of the assessed tree and shrub groups in the sample area to the overall values (Fig. 4). In 2016, the Shape Index value of EFA tree and shrub groups was 1.56, which decreased to 1.49 in 2017. This means that based on their SHAPE value, these groups are more stable. A similar change can be observed for non-EFA elements. In 2016, the SHAPE value was 2.21, while in 2017 it decreased to 2.10. As for ponds, there is no change over the two years.

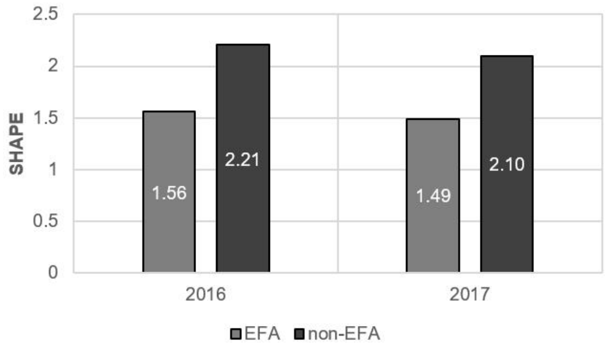

Fig. 4 Changes in the Shape Index of the assessed tree and shrub groups in 2016 and in 2017

Differences in the assessed elements

Although we could get a relatively relieving result when examining the Shape Index and Fractal Dimension Index of the assessed elements, as EFA elements have lower values, yet concerns for valuable landscape elements are not unfounded. The following examples demonstrate that for elements of each dimensional type (point, linear and polygonal), valuable elements have not been selected in all cases as EFA elements.

In the case of point landscape elements, the main groups are shadoofs, tumuli and individual trees. The comparison of the following two individual trees is an instructive example. The Populus in Figure 5a (2016) and 5b (2017) is not listed as an EFA element, despite meeting all prerequisites. The tree in Figure 5c (2016) and 5d (2017) is an individual tree EFA element in MePAR even though it barely fulfils the preconditions.

Fig. 5 Non-EFA individual tree (a and b) and EFA individual tree (c and d) in 2016 and 2017 (K. Máté)

Fig. 6 Officially non-eligible tree lines in 2016 and 2017 (K. Máté)

Tree lines in Figure 6a and 6b are officially not regarded as EFA elements, despite their very significant role in the landscape structure both as a habitat and as a protection for arable lands. They can be defined as significant landscape character elements in the intensively cultivated agricultural landscape.

Among polygonal elements, the greatest contrast was discovered regarding ponds. In Figure 7a (2016), the pond (a former borrow pit) fulfils all criteria, has clean water, is surrounded by arable lands but also by a lakeside margin. Its ecological value is outstanding in its area, a high diversity of species was observed during the field surveys, it is a favourable bird resting place. Still, it is not EFA eligible. However, the former borrow pit which dried up and became filled with soil (Fig. 7b (2016)) is eligible. The difference between the two landscape elements is obvious, the difference in their EFA eligibility is harder to grasp. No change was found in these two ponds during the 2017 field survey. The pond with a large open water surface is still not EFA eligible, while the EFA eligible pond still has low ecological value. The only change regarding the latter is that dry trees standing on the side of the lake bed have been removed by 2017.

Fig. 7 Non-EFA eligible (a) and EFA eligible (b) ponds in 2016 (K. Máté)

Changes in eligibility and conditions

During the 2017 survey, on numerous occasions, the decrease or complete cessation of the eligible area of a landscape element was observed. The field margin in Figure 8a (2016) and 8b (2017) was placed in the category of permanent, not sensitive grasslands in 2016. As for its species composition, it was mostly composed by agricultural weed species. By the 2017 field survey, the grassland field margin could not be found any more: it has been cultivated together with the field and was sowed with sunflowers.

Fig. 8 A disappeared permanent, not sensitive grassland field margin in 2016 (a) and in 2017 (b) (K. Máté)

DISCUSSION

Based on the results it can be stated that the concerns of experts regarding appropriate designation of greening elements is well-founded. No significant difference can be demonstrated between SHAPE and FRAC values of EFA-eligible and non-eligible elements, the year-to-year changes however show a rising trend in the ecological stability of patches. It has to be added though that no far-reaching conclusions can be drawn from a two-year set of data. The minimal change in SHAPE and FRAC values can be explained by the fact that two surveyed tree and shrub groups were EFA-eligible in 2016 but were removed from the MePAR layer for eligible elements in 2017 – thus, there was a difference in the number of elements in the EFA and non-EFA groups. Still, the experiences of the field survey imply that there are certain eligible elements which are ecologically insignificant, and there are “not protected” elements which represent significant ecological value and can contribute to the structural stability of the landscape. The shrinking of eligible areas on MePAR layers did not appear in the landscape in the range of one year, no significant felling took place from one year to the other in tree and shrub groups or in tree lines.

These hidden pitfalls however may have their effect on the landscape structure elements in the long term. The area shrinking of officially eligible tree group patches in MePAR may be followed by an actual shrinking in reality. The slow but gradual expansion of fields at the expense of dirt roads or grassland field margins is a commonplace issue, as it was shown. Similar problems can be expected regarding tree and shrub groups – the unified area-based subsidisation and the hectare-based support of greening may both be incentives for farmers to keep only those patches for which they can receive subsidies. Ecological values play no significant role in these cases.

The decrease of SHAPE values of the EFA elements from 2016 to 2017 can be seen in Figure 2. The 0.07 decrease does not allow for far-reaching conclusions, also because of the low number of elements; however, there are real changes in areas and shapes behind this figure which bring a demonstrable result based on the methodology. The changes of SHAPE values of tree and shrub groups seen in Figure 4 can be traced back to similar reasons. Of the surveyed elements, two EFA tree and shrub group elements have disappeared by 2017 (number 031 and 035), thus farmers could not receive subsidies for their preservation this year. The SHAPE and FRAC values of elements 002 and 004 have decreased, while in case of element 034 only the SHAPE value has changed. The decrease of the overall value shows a positive change in the patch shapes regarding ecological aspects.

In Figures 2, 3 and 4, a small change can be demonstrated for non-EFA elements. The reason behind this may be the reclassification of two formerly EFA tree and shrub groups to the non-EFA group in 2017. As for the SHAPE and FRAC values of individual non-EFA elements, no change can be demonstrated based on Table 1. This stagnation is due to the fact that unlike annually updated MePAR layers for EFA elements, there is no annually updated patch designation for non-EFA elements. Therefore, an annual change for non-EFA elements can be demonstrated only in case a significant change in area can be perceived during the field surveys which can be represented in a GIS system. Comparing the areas of EFA and non-EFA elements is thus recommended only with great caution.

As Table 1 shows, *Robinia pseudoacacia* is the dominant species in a major part of tree and shrub groups in the sample area. The composition of vegetation is a key in defining the ecological values. Unfortunately, the occurance of native woody plants is scattered, and they can be mostly found in the highly protected national park areas. Thus, greening landscape elements marked as protected and ecologically significant are in most cases actually patches consisting of the invasive *Robinia pseudoacacia*.

CONCLUSIONS

In the study, the shapes of 22 patch-like greening landscape elements and the landscape metrics analysis of their changes over two years is shown. Based on landscape indices, patches have become more compact from 2016 to 2017 according to both the Shape Index and the Fractal Dimension Index. However, the positive trend displayed by these patch indices are overshadowed by the findings of the field survey, namely that the dominant species of all patch-like element was the *Robinia pseudoacacia.*

The experiences of the research amplify concerned voices regarding the success of greening. It is important to emphasize that financial incentives do not lead farmers towards the goals that had been originally defined. The fundamental goal of greening is the protection of biodiversity – however, the inappropriate EFA designation renders its achievement impossible, if tree groups consisting of invasive species and dried-up lake beds are also eligible for support and protection. It is necessary to raise the awareness of farmers to the ecological values of elements like tree lines consisting of native species, tree groups hiding nests of birds of prey or lakes with permanent water surface.

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DROUGHTS AND LOW WATER LEVELS IN LATE MEDIEVAL HUNGARY II: 1361, 1439, 1443-4, 1455, 1473, 1480, 1482(?), 1502-3, 1506: DOCUMENTARY VERSUS TREE-RING (OWDA) EVIDENCE

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Abstract

As a continuation of the first paper from the late medieval drought series related to medieval Hungary, we present, analyse and compare further late medieval drought data, based on contemporary direct and indirect written sources. The evidence derived from documentary sources referring to the droughts and dry spells in 1361, 1439, 1473, 1480, 1482(?), 1502-1503 and 1506 are further compared to the recent tree-ring based hydroclimate reconstruction of the OWDA (Old World Drought Atlas), and similarities, differences and complementary information are discussed in more detail. Additionally, documentary evidence related to Danube low water-levels of 1443, 1444, 1455 and 1502 are as well presented in a broader context: these cases provide evidence on the hydrological conditions of the Upper-Danube catchment, and not on the Carpathian Basin. The OWDA evidence in most cases shows good agreement with the discussed documentary-based drought reports, some differences in the spatial extension and intensity of the drought were only exceptionally detected (e.g. 1455, 1507). Most of the written documentation refer to droughts that covered more than one calendar years.

Keywords: droughts, late Middle Ages, low water level, Danube, documentary evidence, OWDA

INTRODUCTION

In the present paper eleven confirmed or presumed drought years, occurred in the Carpathian Basin, are discussed based on direct and indirect documentary evidence, also taking into consideration the tree-ring based annual summer precipitation and spring-summer PDSI reconstructions of the Old World Drought Atlas (see Cook et al., 2015). As Kiss and Nikolić (2015) suggested in the first paper of the current series on medieval droughts, when reported, the memorable drought events are often one year after the Western and West-Central European ones in contemporary Hungarian sources. Nevertheless, indirect information in contemporary domestic sources or foreign documentation may also suggest that, in case of 1362, 1474 and 1507 already the year before, namely in 1361, 1473 and 1506, while in case of 1479 also in 1480, larger areas of the Carpathian Basin might have also suffered from the lack of sufficient precipitation. Moreover, in some additional cases documentary evidence is available concerning drought years or very dry summers in 1439, 1482 and 1503, and in four additional cases, in autumn 1443, spring 1444, summer 1455 and probably also in autumn 1502 low or very low Danube water levels were reported.

Combining and complementing the information presented by Kiss and Nikolić (2015) with the currently discussed evidence, on the one hand, in the present paper some "more complicated" and indirect source evidence is also analysed in a Central European context. On the other hand, the information derived from documentary evidence is compared to the recently published, tree-ring based, annually resolved hydroclimate reconstruction available in the Old World Drought Atlas (hereafter OWDA).

Additionally, in the present paper some auxiliary information on weather background (e.g. winter snow, heat, rainfall and flood reports) is also included. As large part of the annual precipitation in the most populated, major agricultural areas of the country fell in late spring and early summer time, and the cereal and hay harvests strongly depended especially on the May-June, and partly on winter(-early spring) precipitation, potentially there is a significant connection between reported droughts, usually mentioned in relation with harvest problems, and the evidence presented by the OWDA. Furthermore, in case of the tree-ring based hydroclimate reconstruction, the precipitation conditions of the preceding autumn can as well influence tree growth (Prokop et al., 2016).

APPLIED DOCUMENTARY SOURCES AND THE OWDA DATABASE: STRENGTH AND WEAKNESSES

Documentary evidence

As demonstrated by Kiss and Nikolić (2015), mainly individual reports on droughts are available in an increasing number towards the second half of the 15th century. These cases were usually recorded due to the impacts of droughts, and therefore the beginning of the drought period is rarely known, while some of the major consequences – either affecting transportation or harvest results – were mentioned in more detail. Although it is clear that not all the late medieval droughts can be detected in this way, by the 15th century, especially concerning its second half, written documentation enables us to determine greater drought events that affected larger regions of the country.

The presently discussed cases are mainly known from town and diocese accounts (1443-3, 1455, 1502-3, 1506), but narrative sources such as Hungarian and German chronicles (years 1439, 1473, 1480) and charter evidence (1361, 1482) as well play an almost equal role in the available documentation. At present two account series are known that contain weather- and water-level related data in larger quantity: the Pressburg/Pozsony (Bratislava-Sk) accounts and the account books of the bishop of Eger, Ippolito d'Este. Both in source type and content, the short reports available in the accounts of the Eger bishop (E. Kovács, 1992), form a separate group: in these cases only very indirect information is available that generally suggest unfavourable conditions: through one-one bad year for bees with shortage of honey and wax, damaging thunder reports or significant loss of sheep we may presume previous unfavourable conditions that might have been partly (or mainly) related to droughts. As for the narratives, the Thuringian chronicle of Johann Rothe refers to a drought in Hungary under the year 1439, while the Hungarian chronicle of Antonio Bonfini reports on droughts in 1473 and 1479. Similar is true for the known charter evidence related to the drought in 1361-2, and the very dry summer of 1482 or 1483.

Concerning the calendar dating applied, in the present work the original dates in Julian Calendar are provided. Nevertheless, in those cases when the difference between the Julian and Gregorian Calendars affects the interpretation, also the Gregorian Calendar dates (hereafter GC) are provided in brackets.

Application possibilities of the OWDA evidence in drought severity detection of single years

The recently published OWDA maps present natural hydroclimate variability based on tree-ring data in annual resolution: the maps provide June-August scPDSI (Palmer Drought Severity Index) information, and reflect on spring and summer soil moisture conditions year by year concerning the period between 0 AD to 2000 (Cook et al., 2015). Thus, it describes a key period from the viewpoint of, for example, agriculture, but does not offer an evidence on the precipitation or soil moisture conditions of the entire year. In generating the annually-resolved maps, regression-based climate field reconstruction method has been applied which also means that in an area where no tree-ring based hydroclimate reconstruction is available, the closest available series will have the most influence and mainly this/these (and lesser extent the further-located series) will form the basis of extrapolation.

In the OWDA database (Cook et al., 2015), concerning the Carpathian Basin including the Carpathian Mountains, four series area available. The closest data series, and the only one that extends back in time to our late medieval study period with a sufficient amount of sample, is the recent millennial hydroclimate reconstruction of Prokop et al. (2016). In this reconstruction the oak tree samples were derived from different parts of Slovakia, from the northern parts of the Carpathian Basin, in the Western Carpathians. The reconstruction usually explains around or less than 50% of the variables, but correlation also varies over time. Furthermore, whereas until the end of the 14th century the number of annual samples is rather low that determines applicability (see Prokop et al., 2016: Fig. 2A), from the early 15th century onwards the reconstruction is already based on a more sufficient, representative number of samples (exceeds ca. 30-50, and then 100).

Another important point of the reconstruction is spatial correlations: whereas the Slovakian series shows the strongest correlations to the Czech and Western Ukrainian series, this correlation is somewhat weaker, though still significant, with Western, North-western and North-eastern Hungarian series from hilly areas. As no tree-ring based hydroclimate series are known from, for example, the Great Hungarian (or Pannonian) Plain or Central Transylvania, it is not clear in what extent the Prokop et al. (2016) series can describe the hydroclimate variability of these areas. We also have to account with other potential uncertainties. For example, it is generally also possible that after a significant drought year or years the tree 'overreacts' in the following year, and even if the year is not extraordinary humid, the tree produces the signs of very wet conditions. While, according to recent observations, this is clearly true on the seedling level (see e.g. Turcsán et al., 2016), it is also a realistic possibility in case of the adult tree population that forms the basis of hydroclimate reconstruction (see Dobrovolný et al., 2017).

Despite the fact that the reconstruction only covers the spring-summer period, and also the potential uncertainties that make tree-ring based hydroclimate reconstruction a safer tool for multiannual than annual comparison, the aforementioned OWDA maps and the database behind provide an exceptionally valuable, indirect source of information. Its importance gets particularly high when, for example, in documentary evidence only indirect or non-contemporary sources, often with uncertainties in dating, reflect on one-one drought period. In these cases the tree-ring based hydroclimate reconstruction can support or weaken the validity of the information derived from documentary evidence.

RESULTS

The drought year of 1361

In the previous paper of the series (Kiss and Nikolić, 2015), spring 1362 drought information from Dalmatia was presented, together with the presumed early grapevine harvest data, probably suggesting altogether rather warm late spring-summer conditions in the Budapest area in spring-summer 1362. As we could already see, in Middle-Dalmatia the drought started earlier, so that latest the winter could be notably drier than usual.

From further, contemporary Austrian charter evidence it is known that in 1361 there was very bad grain harvest in Austria, in the Czech Lands and also in Hungary (see e.g. Csendes and Oppl, 2001; Rohr, 2007; Kiss et al., 2016), but in Austria already 1360 was a drought year (Rohr, 2007). The fact that already in mid-spring 1362 the Hungarian king prohibited grain export in Dalmatia (in Raguza/Dubrovnik-Hr) from his territories in general (Gelcich and Thallóczy, 1887), further supports the idea that bad-harvest problems affected large parts of the areas of the Hungarian crown. In the meantime, most parts of Western and Central Europe, including such neighbouring countries as Poland, the Czech Lands and Austria, faced with a serious drought in 1361, while in Austria already 1360 was a drought year. Furthermore, apart from the bad grain harvest in 1361, in Austria vine harvest was reportedly bad as well (Alexandre, 1987; Brázdil and Kotyza, 1995; Rohr, 2007).

In Hungary bad or very bad grain harvests were often related to lack of sufficient amount and type of precipitation in the late spring-early summer period, and often already winter was (cold and) dry, then crops could not develop properly. In the Middle Ages such cases were reported, for example, related to the drought year of 1507 (see e.g. Kiss and Nikolić, 2015, Kiss, 2017), but already the mid-14th-century biographer of King Louis I, János Küküllei (Florianus, 1884), listed drought among the most important factors being responsible for famines in Hungary.

As demonstrated by the OWDA maps (see Fig. 1), based on tree rings, 1361 was particularly dry in summer, but soil moisture, very necessary to the development of crops, was perhaps at a loss in spring and summer. In case of such a very strong negative PDSI values, we cannot exclude the possibility that low soil moisture was already a problem before spring 1361. It is, however, and interesting fact that the winter or early spring of 1361 was not dry at least in some parts of the Carpathian Basin: for example, in early spring (possibly in March) along the ford between Lake Fertő/Neusiedlersee and the Hanság/Wasen wetlands cold weather and much snow, while in mid-April the great mud obstructed perambulations (Dreska, 2001). In the meantime, in the hilly north, in Turóc county (today N-/NW-Slovakia) the great snow similarly obstructed a perambulation in mid-March (HNA DL 90540; see Kiss, 2016). This is in slight contradiction with, for example, reports from Austria and Germany where this winter had a cold, but mainly dry character (see e.g. Alexandre, 1987; Brázdil and Kotyza, 1995).

Combining the aforementioned indirect evidence, it seems rather probable that 1361, and spring-(early-)summer in specific, was extraordinary dry, and to some extent this dry tendency also continued in (early) 1362. However, unlike in large parts of Central Europe, the winter of (1360-)1361 was not necessarily dry in Hungary.

1439: very dry (spring-)summer in South-Hungary?

A rather interesting report was preserved in the German *Düringische Chronik* of Johann Rothe (Liliencron, 1859), under the title "*801. Wie die Torcken yn das lant zu Ungirn quomen*". According to the description, the summer of 1439 was dry in Hungary, and the water called "*Mossir*" also dried up ("*Nu was der sommer etzwas dorre unde trocken, alsso das yn den landin das wassir gnant die Mossir gar vertruckent was,...*"). Afterwards, the author

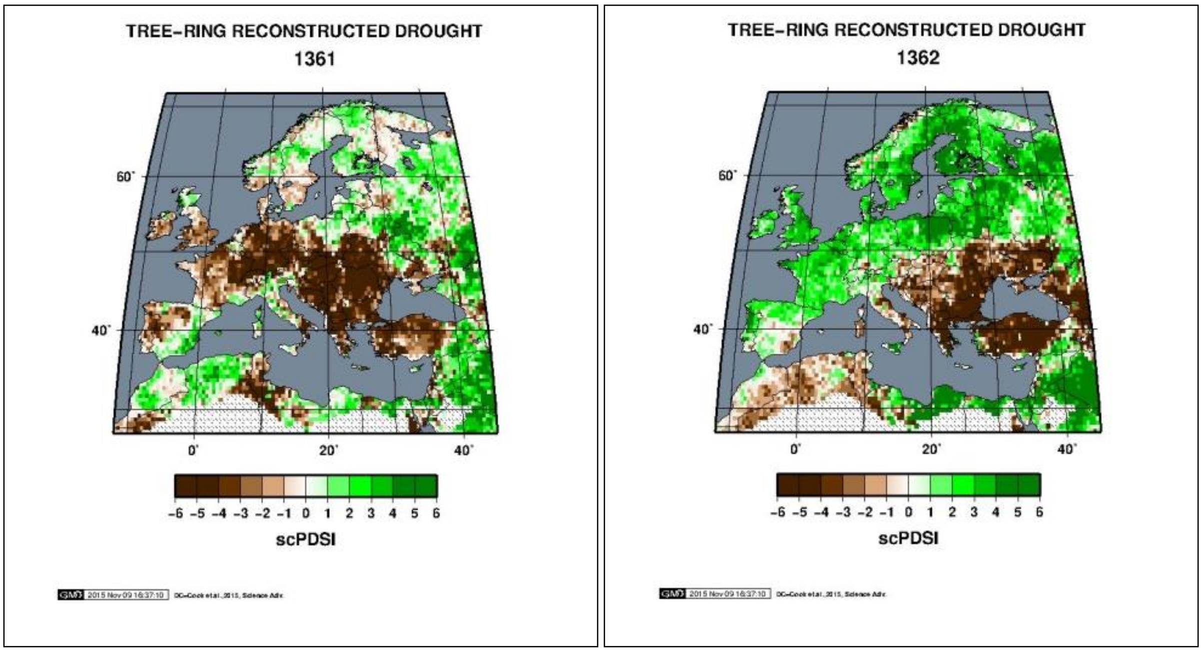

Fig. 1 Tree-ring based hydroclimate reconstructions of the OWDA: 1361 and 1362 (Cook et al., 2015)

shortly described the Turkish campaign and the Hungarian military response, especially in the Banat area that is today North-eastern Serbia and South-western Romania.

The description of the military operations fits the author's dating: in 1439 summer a significant Turkish army first invaded Serbia, and then indeed entered Hungary, attacked the the Banates of Temes and Szörény (centre: Szörényvár/Turnu Severin-Ro), the areas in South Hungary most easily reachable both from Serbia and Valachia. The Hungarian king, Albert, sent an army (with János Hunyadi in lead) to defend especially Szörény against the Turkish attack (see e.g. Bánlaky, 1931).

There is no any known, significant water body in this area that holds the "*Mossir*" name. However, it is possible that the word in the present case does not cover a proper noun, but it is a somewhat distorted form of the Hungarian word of "mocsár" in the meaning of swamp or wetland. If the lowland marshes/swamps/wetlands "quite much" dried up, for example, in medieval Southern Hungary, this circumstance naturally provided more favourable environmental conditions for travel or military campaigns with increasing the possibilities of a quick march and swift attack.

The original author of this volume, Johann Rothe (1360-1434), was the clerk or notary of the town Eisenach in Thuringia. Nevertheless, he died in 1434, and the name of the author who continued his chronicle and also wrote the 1439 Hungarian report, is unknown. Even if it is rather possible that the author who continued Rothe's chronicle was contemporary, missing the author's name, this statement cannot be proved with certainty. Furthermore, the author's description most probably relied on the observation of other people, even if based on the potential interpretation of the word "*Mossir*" we can raise the possibility that the person from whom the unknown author heard the 'story' could be from Hungary. With regards to the dating of the event, as described above, there was indeed a siege of Szörényvár (Turnu Severin-Ro) and a military campaign of the Hungarian army to Serbia in summer-autumn of 1439 (see e.g. Bánlaky, 1931).

According to the tree-ring based hydroclimate reconstruction of the OWDA, around the turn of the 1430-1440s two summers were particularly dry in the Carpathian Basin: 1439 and 1440 (see Fig. 2). The quite dry marshes(?), in accordance with the OWDA scPDSI values, may also suggest that this dry spell started earlier, and probably already spring was drier than usual and, as mentioned before, the political circumstances also support the author's dating of the event to 1439. Furthermore, the fact that the Turkish emperor, Murad II started his military campaign against Serbia in late May (see e.g. Bánlaky, 1932), and was already in the borderline area with his army in June, suggest a quick military campaign that is rather unlikely to happen, for example, in wet weather conditions.

Danube low water levels in autumn 1443 and spring 1444

Although in the Pressburg/Pozsony (Bratislava-Sk) accounts references on floods appear much more often (see e.g. Kiss, 2018), occasionally Danube low water levels are also mentioned. In the first case, on 13 September (GC: 22 September) in 1443, the Danube was noted for being very small (AMB, K6/77: *Item am phinztag noch Nativitate Marie virginis hab wir land in daß wasser geczogen haben als di Tuna gar klain waß…*). Furthermore, in next spring, on 11 April (GC: 20 April) 1444 a reference on small Danube was again included in the accounts (AMB, K7/171: *Item am*

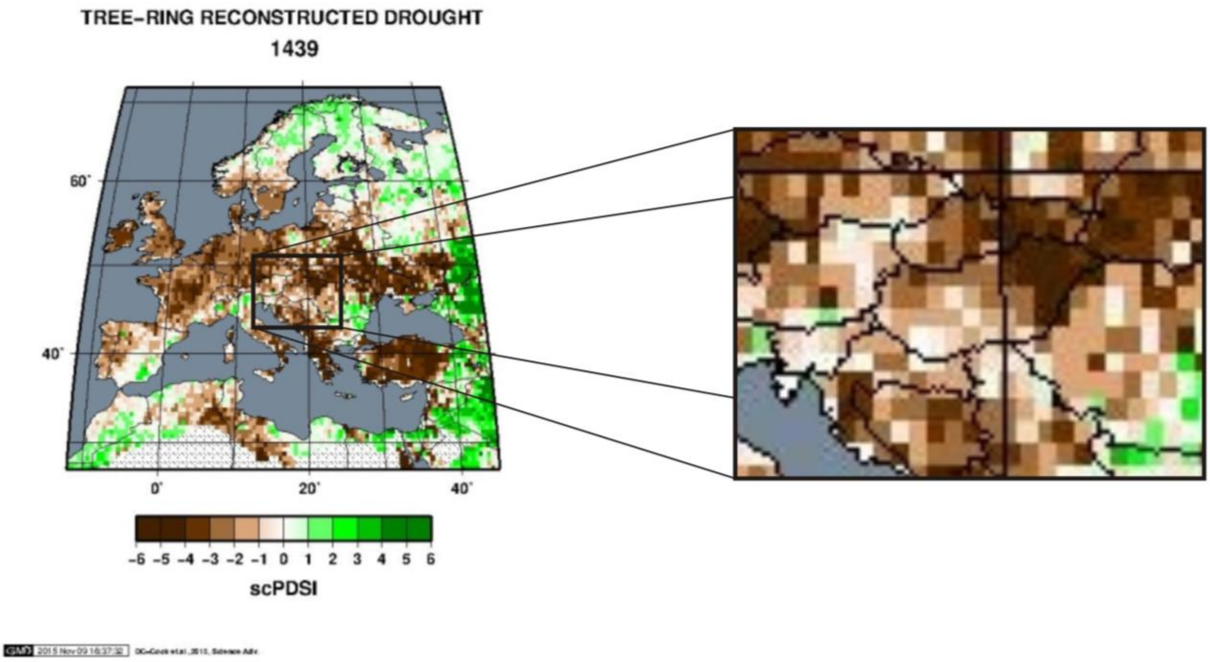

Fig. 2 Tree-ring based hydroclimate reconstruction of the OWDA from 1439, and the reconstruction detail of the Carpathian Basin and its immediate neighbourhood (see Cook et al., 2015)

Sambstag am heiligen Oster obund hab wir gehat xiiij aribater dy Sannd uber dy Tuna uber gepracht haben, in ainer Zullen als dye Tuna klain waß,…).

As the Danube low-water reports come in both cases from the area near the Austrian borderline, the information holds a precious hydroclimate signal concerning the precipitation conditions of the preceding months, primarily referring to the Upper-Danube catchment basin. Thus, these data do not directly reflect on dry periods in the Carpathian Basin, but they primarily correspond to the weather conditions of more westerly areas.

It is interesting to further note that no flood was reported in the accounts between early August 1443 and mid-July 1444 (see Kiss, 2018). Nevertheless, while in July a Danube flood was mentioned (AMB K6/75), in mid-September the water level, reported by the same source in the same volume written by the same hand only three pages later, was already very low. In relation with the three low water-level mentions, concerning 1443 we can find a 'perfect fit' with the relevant OWDA map: based on tree-ring evidence in the (spring-)summer period, great drought prevailed in West-Central Europe in this year.

The Central European documentary evidence provides rather interesting though somewhat biased further information concerning the years 1443 and 1444: whereas the wine harvest was good at Lake Constance in 1443, which suggests overall warmer and drier summer-early autumn conditions, Lower-Austrian and Czech sources speak about rains and windy conditions from mid-July, presumably also in autumn (see e.g. Brázdil and Kotyza, 1995). Nonetheless, in fact the summer and autumn of the previous year, 1442, was memorably dry, followed by a cold and snowy winter that lasted until late April; in some areas snow even fell after that, in early May. The winter of 1444 started early and was memorably hard not only in Central Europe (Brázdil and Kotyza, 1995; Rohr, 2007; Glaser, 2013), but also in the Balkan Peninsula (e.g. Telelis, 2008). In late autumn-early winter time a major military campaign, probably also supported by low waters and overall dry late autumn conditions on roads, was led by the Hungarian king through the Northern Balkan as far as Bulgaria and the Black Sea (see e.g. Bánlaky, 1931). Whereas the winter was dry in Silesia, it was reported with abundant snow in Bavaria, Salzburg and Klosterneuburg. Furthermore, the winter in the Czech Land released only after 17 March (Brázdil and Kotyza, 1995; Glaser, 2013).

Consequently, merely based on the information from Central Europe, the Danube low water-level evidence dated to autumn 1443 and spring 1444 should be better dated to 1442 and 1443. The 'problem' in this case is that the Pressburg accounts are very clearly dated: all previous and following entries could refer only to 1443 and not 1442 in the autumn case, while to 1444 and not 1443 in the spring case. Furthermore, it is also highly unlikely that for works, carried out in 1442 the town would have paid with a year or even several months of delay (without even mentioning that). It is also an interesting fact that, while the dates in the relevant section of the accounts clearly and unambiguously refer to 1443 in volume (AMB) K6 and to 1444 in volume K7, no information on low-water level conditions remained in the previous, 1442 (AMB K4) and 1442-1443 (AMB K5) volumes. It is, nevertheless, somewhat thought-provoking that long-lasting and large-scale works took place in 1442 in the Old Tabor (riverbank, harbour) area, and this would have been rather difficult to carry out during the high water level or flooding of the Danube.

In the present case, the OWDA reconstruction plays a rather important role in sorting out the potential discrepancy in dating the (very) low Danube water level

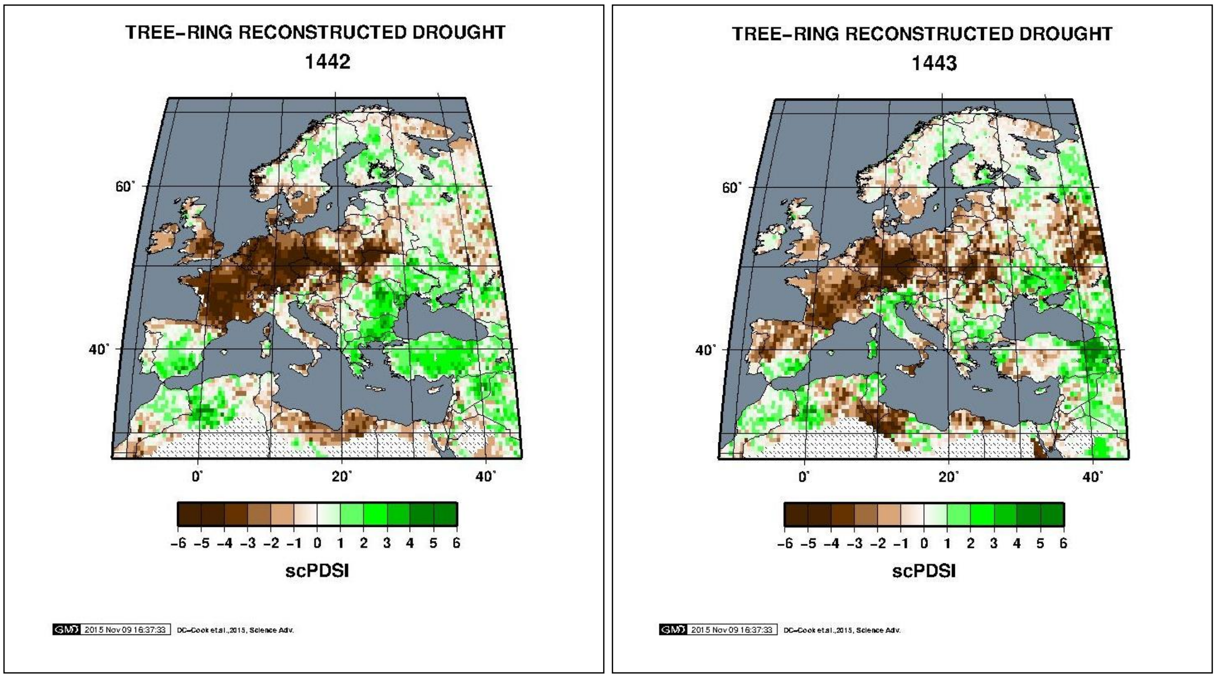

Fig. 3 Tree-ring based hydroclimate reconstructions of the OWDA: 1442 and 1443 (Cook et al., 2015)

reports: according to the tree-ring based hydroclimate reconstruction both in 1442 and 1443 the (spring-) summer period was very dry in the Upper-Danube catchment area (see Fig. 3). On the basis of this and the above-mentioned documentary evidence, it is possible that - although dry conditions and low water levels already prevailed in 1442, due to particular works where related water-level conditions were mentioned, the source only mentioned the low water level of the Danube when because of the payment conditions such an explanation was necessary in particular account entries, namely in autumn 1443 and spring 1444.

Low Danube water level or not? The small-water reference in summer 1455

More than a decade later, the little extension of water was again mentioned in the Pressburg accounts, at this time in summer: on 23 June (GC: 2 July) 1455 the small size of the river was noted (AMB K22a/47: *Item und haben auch gehabt besundere ij aribater pei dem hanns stewber pinter die pewsch gelegt haben als die Tuna klain waß die dass wasser zu dem wasser Rad gelait haben* …). The text clearly refers to low water-level conditions of the Danube river, in the Pressburg/Pozsony (today Bratislava-Sk) area, and also the late June 1455 dating is accurately provided (previous and following dates all belong to the year of 1455) in the account book.

With regards to the potential, documentary-based weather-related parallels in the neighbouring countries, in 1455 the winter was hard and lasted until the end of March in Bohemia, but the spring and particularly the summer could be warm. In summer, heat and great drought was recorded in Silesia (Brázdil and Kotyza, 1995). No information is available concerning the spring, but according to Glaser (2013), the summer was wet and infertile in the German areas. Except for the Eastern Alpine area where mainly dry weather conditions prevailed, the relevant map of the OWDA also shows slightly wet conditions in the Upper-Danube catchment basin, especially in Bavaria, even if dry conditions prevailed in large parts of Austria (Fig. 4).

In conclusion, although the Czech and Silesian sources rather refer to a warm and dry summer, the German reference, partly in accordance with the OWDA evidence, clearly mentions it to be wet. At the moment we cannot solve this apparent contradiction, but it is clear that the Pressburg accounts item is accurately dated, and clear about the Danube low water level. However, as the information comes from early summer, it is probable that more significant precipitation occurred after this date, and it might be also possible that the Eastern Alpine catchment basin of the Danube was predominantly dry in (spring-)early summer, and this circumstance influenced the water level conditions of the Danube in Eastern Austria and Hungary.

Drought in 1473, and 1474 revisited

In relation with the "perennial" drought report of the contemporary chronicle writer, Antonio Bonfini, who dated the event to 1474, three other, non-contemporary sources were listed by Kiss and Nikolić (2015) considering a great drought, referred under the year 1473. While one of the non-contemporary sources, the compilation of the Swiss Lycosthenes, was written in the mid-16th century, two other, 17th-century chronicles, the chronicle of Leibic/Leibitz (L'ubica-Sk) town and the chronicle of Caspar Hain from Lőcse/Leutscha (Levoča-Sk) both from the Szepesseg/Spiš region (today in NE-Slovakia), reported on a great drought that happened in 1473 (for references, see: Kiss and Nikolić, 2015).

Thus, on the one hand, a contemporary report is available on a great drought written by Bonfini, a contemporary author of Italian origin, who later lived

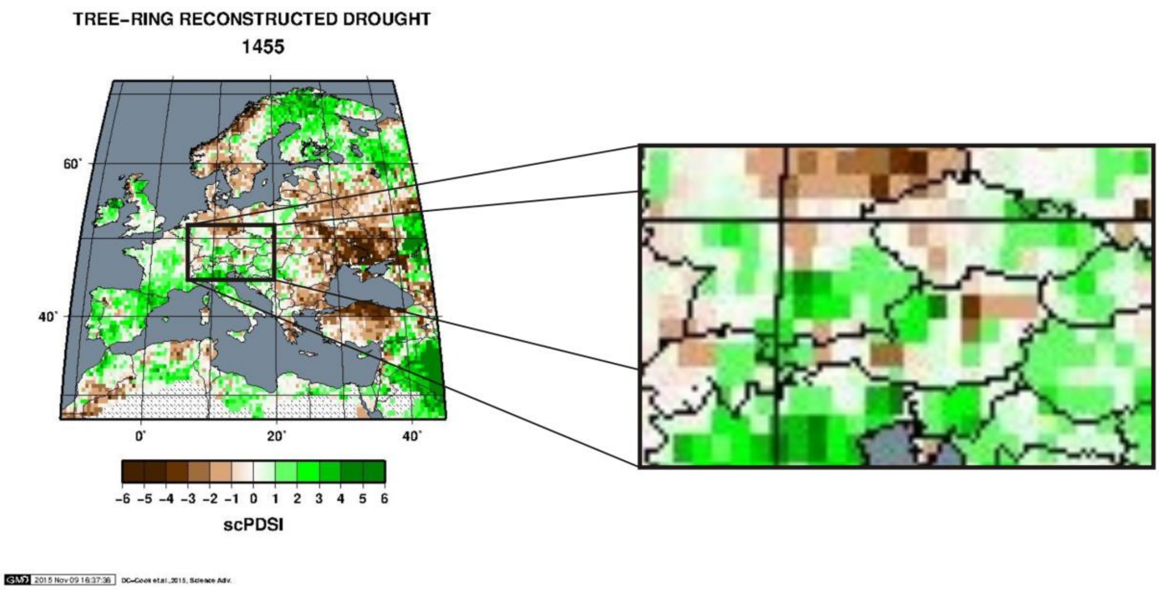

Fig. 4 Tree-ring based hydroclimate reconstruction of the OWDA from 1455, and the reconstruction detail of the Upper-Danube catchment basin (see Cook et al., 2015)

in Hungary, wrote the most detailed and accurate history of Hungary of his time, clearly gained his information from eye-witnesses in Hungary, applied thorough source critics, and accounted for being a most reliable author of the reign of King Matthias (1458-1490; see e.g. Klaniczay, 1974). Bonfini's report provides 1474 dating, with suggesting a long-term drought that allows an interpretation of an event that lasted longer than a year and thus, does not exclude a 1473-1474 dating either, especially, because the author also refers to parallel Turkish attacks that happened both in 1473 and 1474 (see e.g. Bánlaky, 1932).

On the other hand, three non-contemporary chronicles, two of them from Hungary and another one from Switzerland suggested 1473 as the great drought year in Hungary, and none of the three mentioned 1474 in connection with drought. And while, according to the contemporary documentation, 1473 was a great drought year in Central Europe, including the Czech Lands, Poland, the German areas, Switzerland as well as Austria (see e.g. Brázdil and Kotyza, 1995; Glaser, 2013), the sources were mostly silent about the character if 1474 in the same areas. Thus, in this case we have a rather unique situation as the only contemporary narrative that reported on the drought provides a somewhat different (even if no fully contradicting) dating than the non-contemporary chronicles, and the evidence from the neighbouring countries more supports the dating of the non-contemporary sources and not that of the contemporary one.

The relevant OWDA maps, however, show that in the Carpathian Basin there were considerable (spring-) summer dry spells both in 1473 and 1474, even if 1473 seems to be generally more extreme, especially in the northern half of the Basin (see Fig. 5). Nonetheless, in the southern part of medieval Hungary, including the southern borderlines of the kingdom, the drought of 1473 does not appear to be considerably more severe on the OWDA maps than in 1474.

Further documentary-based (even if indirect) information may provide some additional help to solve potential contradictions. As for Bonfini, in his work on the Hungarian history, the drought was only a background information that helped him in the description of military processes (see Kulcsár and Kulcsár, 1974). Thus, he probably mentioned drought only when he felt it necessary in his explanations, while only briefly referred it without specification on date or location (as a circumstance that made Turkish attack easier) when his text did not need this kind of auxiliary information. Moreover, he gained large part of his information about these years from eye-witnesses in or related to the royal court: these eye-witnesses were likely to be the soldiers, or even leaders of military operations, who participated in the military campaigns leading to the south, towards the territories occupied by the Ottoman Empire. These military campaigns, however, mainly took place in 1474 (see e.g. Bánlaky, 1932; Klaniczay, 1974) and not in 1473, and therefore the potential Hungarian eye-witnesses could have personal experience, at least through large part of the country including the southern borderlines, mainly in this year. The extensive wetlands of the lowland areas usually needed longer period of time to dry up: if there was a severe drought in 1473, and 1474 was also dry, the really visible consequences, for example, in the extension of stagnant water bodies or the height of groundwater table could be perhaps even more apparent in 1474 than in 1473.

Additionally, a Silesian source may shed more light on the character of 1474 in the close neighbourhood of the Carpathian Basin. The contemporary Silesian chronicler, Peter Eschenloer (Roth, 2003; Gyalókay, 1940), while describing the successful military campaign of King Matthias against the Polish king in Silesia, noted that the water level of the Oder/Odra was low in early October 1474 at Krappitz (Krapkowice-Pl), when the Polish army crossed it. This fact suggests overall dry preceding conditions in the Southern Silesian catchment

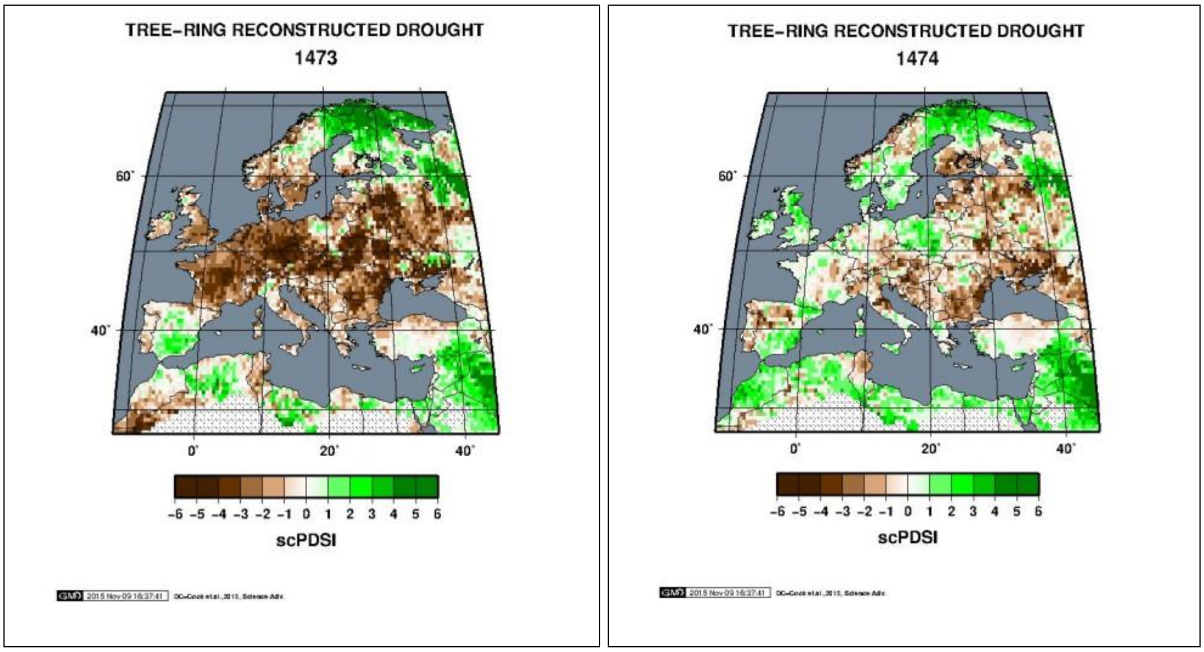

Fig. 5 Tree-ring based hydroclimate reconstructions of the OWDA: 1473 and 1474 (Cook et al., 2015)

basin of the river prior to early October, while the Polish chronicle writer, Jan Długosz, in November mentioned heat and drought (length not defined), and then a flood of the Oder/Odra that had been caused by rain (Bazkowski et al., 2005).

Consequently, in accordance with the aforementioned documentary and tree-ring based evidence, and also with reference to the part-conclusions of Kiss and Nikolić (2015), we suggest that both 1473 and 1474 could be years with more significant water deficit in Hungary and the Carpathian Basin, even if the intensity of this dry spell and drought may have had spatial and temporal differences within the Carpathian Basin.

Religious procession praying for rain: great spring (and summer?) drought in 1480

Briefly referred by Kiss and Nikolić (2015), following the inquiry of king Matthias I, the Pauliners of Budaszentlőrinc made a religious procession in (late?) spring, from Budaszentlőrinc to the Castle of Buda, carrying the relics of the saint (Paul) with them, and praying for rain in the "great drought". However, it started raining before the procession could have turned back to the monastery, and the vegetation recovered (Gyöngyösy, 1988). This information is particularly interesting as the only available report, Antonio Bonfini's extensive chronicle, suggests 1479 as a memorable drought year, and does not mention dry conditions for 1480 (Kiss and Nikolić, 2015). Nonetheless, in, for example, the Czech Lands 1480 was marked by its characteristic dry nature and not 1479.

Another additional, indirect evidence, similarly dated to 1480, might be worth to be mentioned here: the judge of (Buda)Felhévíz warned the tax-collectors to the royal charter that stated their tax-free status on their own cargo ships carrying food (Bártfai Szabó, 1938). Although such a case could happen any time, there is somewhat more chance for food-related conflicts, for example, in times with food shortage problems. It has to be further noted that, documented in the Pressburg accounts, in early summer 1480 there was a Danube flood of moderate intensity in the Bratislava area (see Kiss, 2018).

As presented on the related OWDA maps (Fig. 6), 1479 was a significant drought year concerning at least the (spring-) summer period practically all over Europe, while 1480 was more concentrated to the southern, south-eastern parts of the continent, including the Carpathian Basin. Nevertheless, on the tree-ring based hydroclimate reconstruction map the Carpathian Basin seems to be strongly affected by drought in both years, and therefore in this case – in agreement with the direct and indirect documentary evidence – we have to account with a double drought-year in Hungary.

"In aestate ultra arida"- very dry summer in Transylvania: 1482?

In a charter dated to 19 February 1496 (Iványi, 1928), the nobles of Pókafalva (Păuca-Ro) in South-eastern Transylvania, preserved an earlier complaint against the people of the Pauline friary: in 1482 there was very dry summer, and the serfs ("*layci nostri*") of these nobles drove their draught animals to a fishpond, constructed in 1475, to drink. They went there three times, and finally armed men of the friary came, and gravely injured with their swords two serfs of the nobles ("*In anno quidem domini millesimo quadringentesimo octuagesimo secundo in aestate ultra arida cum layci nostri ad adaquandas iumenta ipsorum ad piscinam dictorum fratrum depulissent, tunc prior praefatorum tertiusmet sibi similibus, armatis manibus de claustro irruentes, duos ex laicis nostris cum gladio letaliter vulnerarunt....*"). The most important, weather-related information of this story is that in 1482 the summer was memorably dry, but there was enough water in the local fishpond to serve as a water supply for large domestic animals.

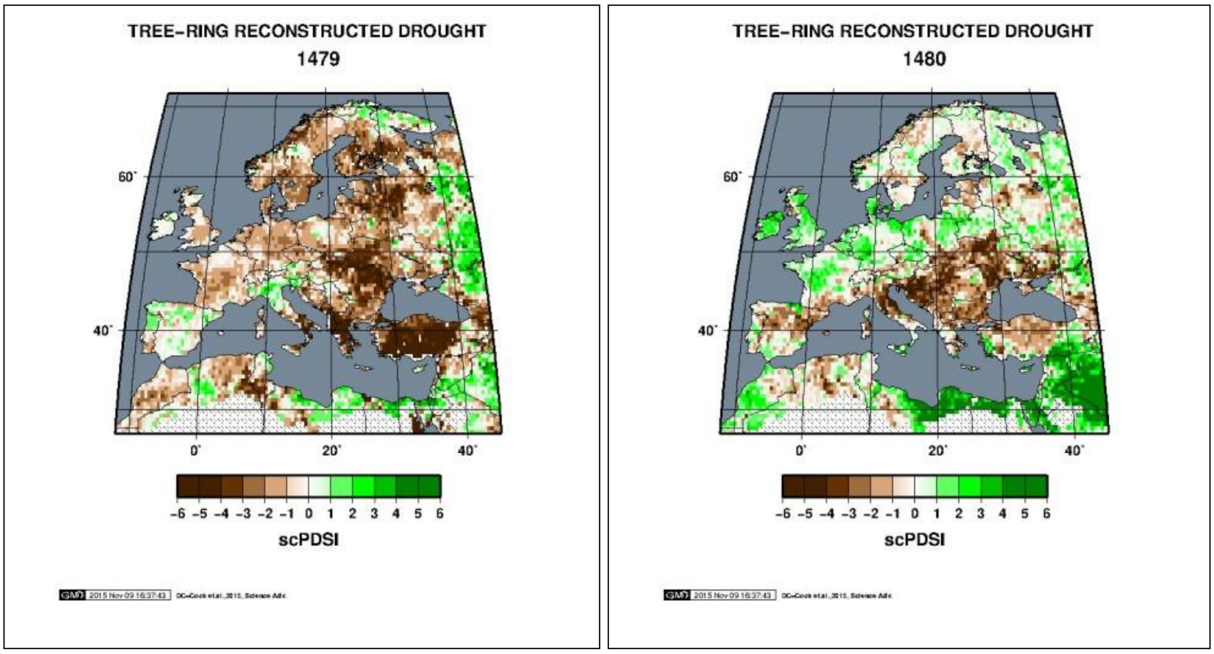

Fig. 6 Tree-ring based hydroclimate reconstructions of the OWDA: 1479 and 1480 (Cook et al., 2015)

The charter was written almost 14 years after the event. Although legal documents, and charters in particular, form a most accurately dated source group, in the present legal procedure the fact that the event happened particularly in 1482 did not play a central role in the legal case and thus, we cannot completely rule out the possibility that the event occurred one year earlier or later. Nevertheless, as the charter itself referred back to 1482 specifically as a (memorable) summer of great drought, it is probable that the event was not misdated, and potentially many eye-witnesses still could confirm the dating.

Taking into consideration the OWDA reconstruction (Fig. 7), however, we can see that 1483 (or even 1484) would be a more likely option for a particularly dry summer in Transylvania. According to the OWDA, 1482 was although dry, it did not represent a particularly dry period in Transylvania. Nonetheless, since the OWDA provides information mainly on (spring-)summer patterns, this might be also in connection with spring (or even earlier) precipitation. North, north-east to Transylvania, the areas what is today the Ukraine show extreme dry patterns for the (spring-)summer of 1482, which may indirectly support the theory of a very dry summer in large parts of Transylvania, too. Therefore, although we cannot exclude the possibility that the year 1482 was mentioned in the charter by mistake instead of, for example, 1483, it is also possible that the charter evidence provide in this case a more accurate information than the OWDA data.

Loss of bee, grain and vine harvest, high prices and low water level: indicators of a dry spell in 1502 and 1503?

In Hungary, no contemporary source is known that directly refers to any dry spell or drought in the years 1502 and 1503. Nevertheless, some indirect evidence suggests that considerably dry conditions. On 29 November (GC: 9 December) in 1502 the small water is mentioned in the Pressburg accounts (AMB, K58/34: *Item Kamerer hat hingeben ain alte pletten ausß dem urfar denn Ungern in das klain wasser zw dem Thaman sthoff*…). The phrasing of the sentence less obviously refers to general low water levels than the ones in 1443, 1444 and 1455. Still, in the text clearly a Danube trajectory and a ship are mentioned, and the sentence is regarding to the actual conditions of a Danube branch. However, as the text refers to an old ship, the most possible option is that the small extension of the water was emphasised because this important circumstance influenced, either positively or negatively, the conditions of removal. Although the reference is dated to late autumn-early winter times, it is worth noting that the OWDA map for (spring-)summer 1502 shows rather dry conditions in Western and West-Central Europe including the majority of the Upper-Danube catchment basin, and the dry character of the autumn could have further supported the development of a dry spell that resulted the 1503 extreme low tree ring values (see Fig. 8).

Documented in a number of contemporary sources and presented by the relevant OWDA map (Fig. 8), 1503 is a well-known severe drought year in Western and Central Europe, also including, for example, the Czech Lands, Poland, Austria or the German areas (see e.g. Brázdil et al. 2014; Rohr, 2007; Glaser, 2013). Thus, both 1502 and 1503 were drought years in Western and North-western Europe, but in (spring-)summer 1503 the drought was considerably more severe. According to the above maps (Fig. 8), however, the Carpathian Basin would have been less affected in 1502, and even in 1503 the drought could have appeared in a significantly milder form than in the West. However, it is interesting that while on the OWDA map the central and eastern parts of Austria,

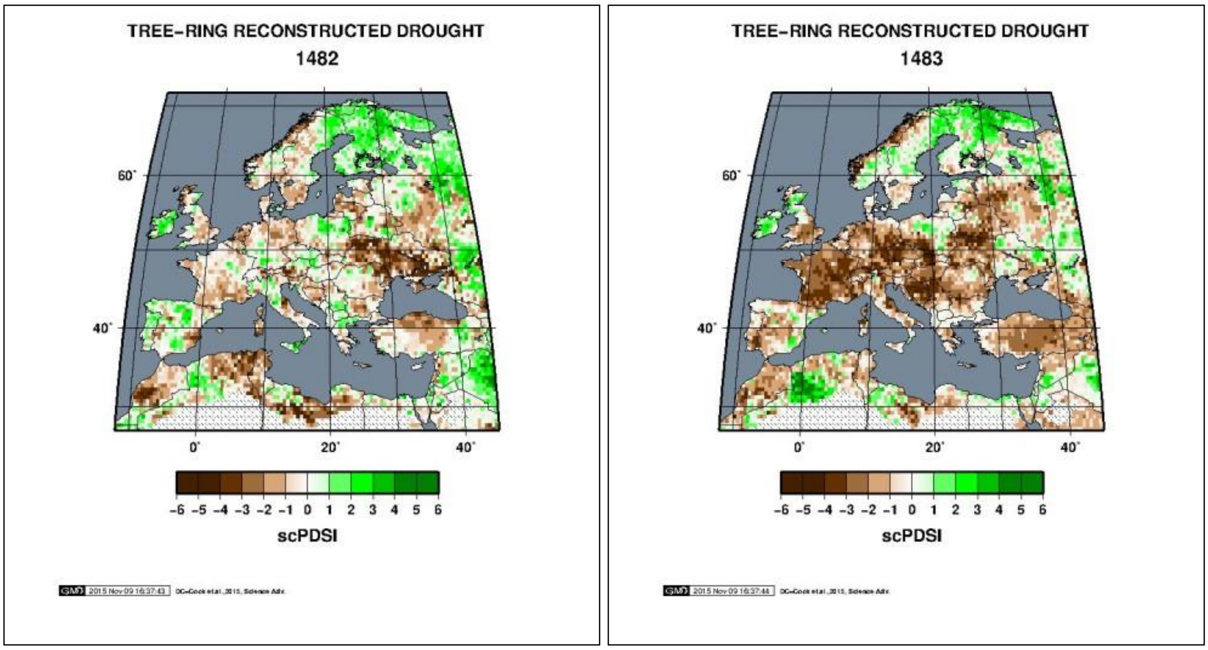

Fig. 7 Tree-ring based hydroclimate reconstructions of the OWDA: 1482-3 (Cook et al. 2015)

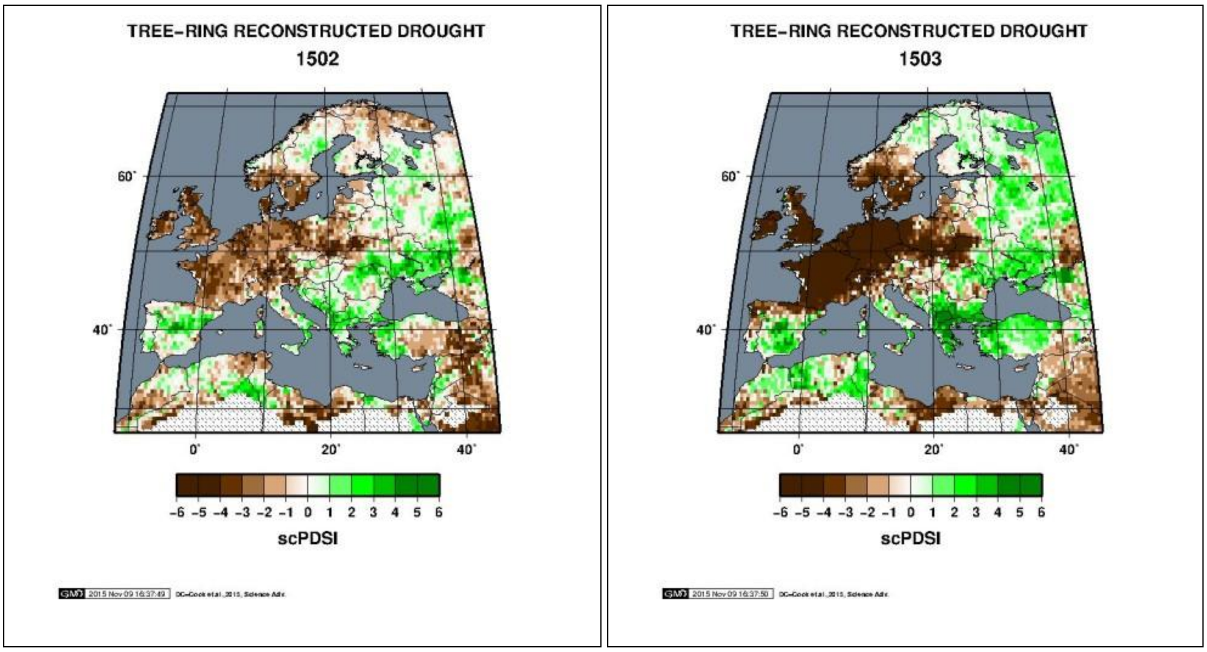

Fig. 8 Tree-ring based hydroclimate reconstructions of the OWDA: 1502 and 1503 (Cook et al. 2015)

similar to most of the Carpathian Basin, do not belong to the areas notably affected by severe drought, the chronicle of Lorenz Mittenauer in Wels (Upper-Austria) clearly emphasised the extreme drought of 1503 and its unfavourable consequences (including devastating hails) on cereal and hay harvest as well as on fish supply (see Rohr, 2007). It is also interesting that, based on documentary evidence, in the Czech Lands there were droughts in 1501, 1503 and 1504, too.

In 1502 or 1503 no direct source refers to a drought in Hungary. Nevertheless, in the rather detailed accounts of the bishop of Eger (source: E. Kovács, 1992) many entries are related to certain problems that later, in 1507, again appear in the accounts when drought and related damages are listed (see Kiss and Nikolić, 2015; Kiss, 2017). Even if the full account book is not available for 1502, rather interesting information is known from the 1503 accounts both concerning 1502 and 1503. No drought was directly mentioned, but much more is known concerning the damaging hails. Mentioned on 14 February 1503, vineyards were previously damaged by hails in Borsod county (e.g. Boldva, Varbó; NE-Hungary): this evidence most probably refers to hails that still occurred in 1502. Furthermore, the high prices of "all things" were mentioned in Eger on 1 March 1503: this information may suggests harvest problems already for 1502.

Damages due to hails, bad weather, or simply the great damages in vineyards without mentioning the cause, occurred in 1503, were reported in the bishop's accounts concerning Kaza in Zemplén county (also heavily affected area in 1507: see Kiss, 2017), Sajószentpéter in Borsod county, (Olasz)Liszka, Gálszécs (Sečovce-Sk) and Nádasd (Tornanádaska) in Újvár county. Except for Gálszécs/Sečovce in South-eastern Slovakia, all settlements are located today in North-eastern Hungary, in Borsod-Abaúj-Zemplén county. In the vine region of the Eger diocese (i.e. Gyöngyös, Gyöngyöspüspöki, Solymos) part of the wine went bad ("rotten") in this year. Damages by hail or simply bad harvest were also reported in Szabolcs county (Nádudvar, Hegyeg) where spring cereals and the oats were destroyed. As presented by Kiss and Nikolić (2015) and Kiss (2017), similar problems were typical during the 1507 drought event. Another negative circumstance was mentioned concerning Eperjes (Prešov-Sk): due to fire, the town received tax release in this year.

A further problem, again rather similar to those described in 1507, was the low income or complete failure in bee products. Even if in 1503 this was mentioned in less cases than in 1507, it could be still a significant general problem in the area of the diocese, especially because larger areas, entire districts, for example the Szántói district in Szabolcs, the Homonnai (Humenné-Sk), Varannói (Vranov nad Topľou-Sk), Sztropkói (Stropkov-Sk), Nagymihályi (Mihalovce-Sk) districts in Zemplén, the Kazai district in Borsod county and the entire Újvár county had no beehives to send to the castle (Eger) in this year. As bees usually react rather sensitively on weather extremes, and this is particularly true in case of drought (or very wet conditions), similar to 1507 (Kiss, 2017), they may act as indicators of weather-, and probably (spring-summer, or earlier) drought-related problems in 1503.

Thus, although currently no contemporary documentary evidence mentions drought related 1502 or 1503, it is clear that both years were problematic in some (e.g. the north-eastern) parts of the country, and based on the parallels of the neighbouring countries as well as the relevant OWDA maps, we may raise the possibility that dry conditions prevailed in some parts of Hungary in 1503, and probably also in 1502. It has to be further added that, despite drought problems, probably not the entire year or years of 1502 and 1503 were dry, and even water surplus might have caused problems in this period. For example, on 6 May 1503 a letter written by the king to the royal town of

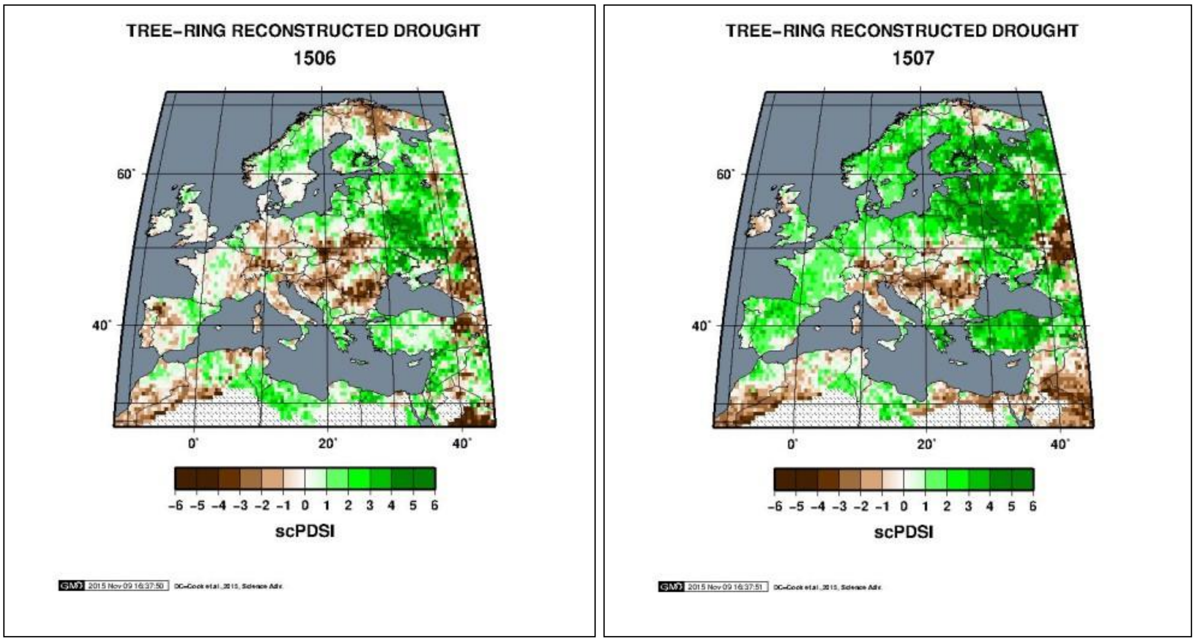

Fig. 9 Tree-ring based hydroclimate reconstructions of the OWDA: 1506 and 1507 (Cook et al. 2015)

Pozsony (Bratislava-Sk) informs us about the severe problems caused by the frequent great floods ("*ex frequenti illuvie aquarum*") in the area of the town (HNA DF 240970; see Kiss and Laszlovszky, 2013), while according to Rohr (2007) there was a great flood with significant damages on the River Traun in September 1503 at Wels in the catchment basin of the Upper-Danube. This flood, together with the potential flood of other rivers in the Eastern Alpine area, might have also influenced the water-level conditions of the Danube in Hungary.

Loss of sheep, high prices and convective events: indirect indicators of a drought in 1506?

As presented by Kiss and Nikolić (2015), 1507 was mentioned by different sources as a memorable drought year in north-eastern part of the kingdom, that is today North-east Hungary, Eastern Slovakia and South-western Ukraine. The other contemporary source, János Kakas in Buda, however, mentioned this drought related to the entire kingdom. Nonetheless, in most parts of Central Europe rather 1506 was reported in contemporary sources as a year with great drought.

The relevant OWDA maps (see Fig. 9) concerning the years 1506 and 1507 show conditions considerably drier than usual, but according to these maps, a notable (spring-)summer drought anomaly could be detected especially in the southern and the north-eastern part of the Carpathian Basin in 1506, and only in the southern parts we see a greater drought anomaly in 1507. In general, based on the OWDA maps, both years were rather dry especially in the south, but drier conditions would have prevailed in large part of the Carpathian Basin in 1506 than in 1507.

Both the information coming from documentary evidence of the neighbouring areas (where detectable) and the tree-ring based hydroclimate reconstruction suggest dry conditions or drought in 1506 in Central Europe, even if the data based on the tree-ring reconstruction suggest a less significant drought event than what is known from documentary evidence. In Hungary no contemporary report is known that directly mentions 1506 as a year of drought. Nevertheless, some indirect evidence suggests that weather/environmental conditions were unfavourable not only in 1507 but already in 1506.

As presented in Table 1, the church of Saint John burnt down in summer 1506 due to thunder in Eger (see Table 1), which means that a significant convective event occurred. Other convective events had resulted the damaging hails that caused particularly great damages, most probably in 1506, in Tolcsva that belongs to the Tokaj-Hegyalja wine region. The lamb tithe problems in Sáros county (Table 1; today N-NE-Slovakia) probably refer to feeding/nutrition problems and/or disease in the 1506, but no details are known. However, according to the relevant OWDA map this was one of the areas affected the most by drought in 1506 (see Fig. 9). In March 1507 there were only a few sturgeon and other fish in Tisza: this fact most probably refers to preceding low water levels, and reflects on the precipitation patterns of a period that covered at least several months prior to the date of mention and thus, most probably already in 1506 the prevailing water levels were lower than usual. As the catchment basin of the Upper-Tisza covers the north-eastern part of the Carpathian Basin (NE-Slovakia, SW-Ukraine) as well as Northern Transylvania (N-Romania), in these areas at least the second part of 1506 had to be drier than usual.

Unlike in 1507 when it seemed to be a significant problem, based on the bishop's accounts, there were no bee-related problems or lack of bee-products mentioned in 1506. However, the full accounts concerning 1506 are missing, and only the references remained in the 1507 accounts are known. Thus, the lack of reference on the problem may not automatically refer to the lack of problems.

Table 1 Problems mentioned in the accounts of the Eger diocese (Source: E. Kovács, 1992; see also: Kiss, 2017)

Date of Account	Location /county	Bad harvest or other damage	Tax release, postponing	Weather-related Evidence
24.07.1506 GC: 03.08	Eger	St. John church burnt		Struck by thunder
after 15.12.1506 GC: 25.12	Buda, Pest	Flood		Very great Danube ice and coldness before
02.02.1507 GC: 12.02	Szabolcs county	Losses (from 1506?): lamb tithe	Paid together with the 1506 lamb tithe	
02.02.1507	Sáros county	Lamb tithe: low income		
14.03.1507 GC: 24.03	Tolcsva (Zemplén county)	Wine tithe: very great damages in vineyards	12 Ft tax release due to previous damages, and for public works	Hails (probably in 1506)
25.03.1507 GC: 04.04	Kürt (at the Tisza river)	Few fish (sturgeon, other fishes)		
24.04.1507 GC: 04.05	Felnémet (Heves county)	Poverty of serfs	Full release of remaining tax due to much public work	

Comparing the OWDA map with the available indirect documentary evidence, it is thought-provoking that in 18 April 1507 the king in a dramatic letter asked the citizens of Sopron royal town to send a 1000 Golden Forint as a special military tax, because he urgently had to pay the soldiers at the southern borderline, due to their extreme great need ("*extreme inopie magnitudo*"; Házi, 1928). This dramatic tone and the grave problems along the southern defence line can be, of course, always explained by the ever-uncertain military situation, as Turkish troops could attack the area any time. The long-term expenses of the mere maintenance of this long defence line in itself meant a significant burden on the annual royal budget. Nevertheless, taking into consideration the relevant OWDA map which shows that in 1506 the southern part of the country was the most affected by drought, it is also possible that in spring 1507 the very high price of food was an even more striking problem in the south than usual. Given the fact that the king was late with the soldiers' payment, they most probably had severe food supply problems that threatened the southern fortresses with desertion. Thus, apart from the general political and socio-economic problems of the south, we might also have to count with the negative effects of actual weather conditions.

CONCLUSIONS AND OUTLOOK

In the present paper, based on direct and indirect, mainly contemporary source evidence and also on the basis of the OWDA maps eleven years with dry spells were discussed. Seven of the discussed cases were suggested as drought events occurred in some parts of the Carpathian Basin, while in further four cases low water-level reports were discussed in more detail. The known low water-level reports in 1443, 1444, 1455 and 1502, were all documented in the Pressburg accounts, and refer to the Danube in the Bratislava area, and therefore primarily reflect not on the precipitation deficit of the Carpathian Basin, but rather that of the catchment basin of the Upper-Danube, including Bavaria and the Eastern Alpine area (Austria).

As presented throughout the paper in a number of case studies, when documentary evidence is available, usually there were not only one but two years affected by drought. In this way, although directly the next (or previous) year was more emphasised in 'local' documentation, some of the great European drought years (e.g. 1473, 1480, 1506) could be also detected regarding late medieval Hungary. Moreover, in some cases it is probable that among the coupled drought years not necessarily the drought year, most severe in Western or West-Central Europe, was the more severe in the Carpathian Basin.

Due to the characteristics of source types applied, it is also a possible option that while one drought year was (occasionally) mentioned in a contemporary domestic source due to related consequences, the other, similarly important (preceding or following) drought year remained unreported or can be detected only in the indirect evidence. This is true not only for the direct drought references, but also to the other important source group that concerns Danube low water levels. For example, the 1443 or 1444 low waters were recorded in relation with particular activities, and therefore even if the previous year would have meant a similar or even greater anomaly, could easily remained unreported.

Furthermore, in some of the cases it is also possible that while in the first year one part of the country was more affected, in the other year the drought was more severe in other parts (e.g. 1473-4, 1506-7). The OWDA maps also show that, even if there were anomalous drought years that affected majority of Central and Western Europe, similar to modern droughts, in most cases we have to account with considerable spatial differences not only between the different parts of Europe, but also compared to the neighbouring countries, and even within the Carpathian Basin itself.

Although occasionally, especially concerning intensity and spatial extension of one-one significant drought events, some differences occur (e.g. in 1507), in most cases we found fairly good agreement between the (spring-)summer hydroclimate reconstruction of the OWDA and the documentary-based drought information. Moreover, in some cases the OWDA map provided a good support to the identification of drought years, documented only in one contemporary source in Hungary, but with scarce or no parallel information in the neighbouring countries. This might be particularly important in case of two or more drought years in series (e.g. 1442-1444). We also have to add that, rather clearly, many of the dry spells, captured in tree-ring evidence, still could not be detected in the domestic written documentation. However, rather indirectly other sources (e.g. food shortage problems and the OWDA-based long drought periods), not (yet) discussed in this and the previous paper, may provide further data that helps to capture more signs of severe droughts in late medieval Hungary.

The 15th-century dry spells, detected in written sources, are to some extent clustered around two periods: the first such period is the late 1430s-early 1440s: here 1439, 1443 and 1444 addressed in documentary evidence. Nevertheless, the OWDA as well as the information from the neighbouring areas suggest that also years in between (i.e. 1440, 1442) were considerably dry in Central Europe and probably also in Hungary, in the (spring-)summer period. Taking into consideration also the evidence presented by Kiss and Nikolić (2015), the other such period is concentrated around the 1470s-early 1480s.

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